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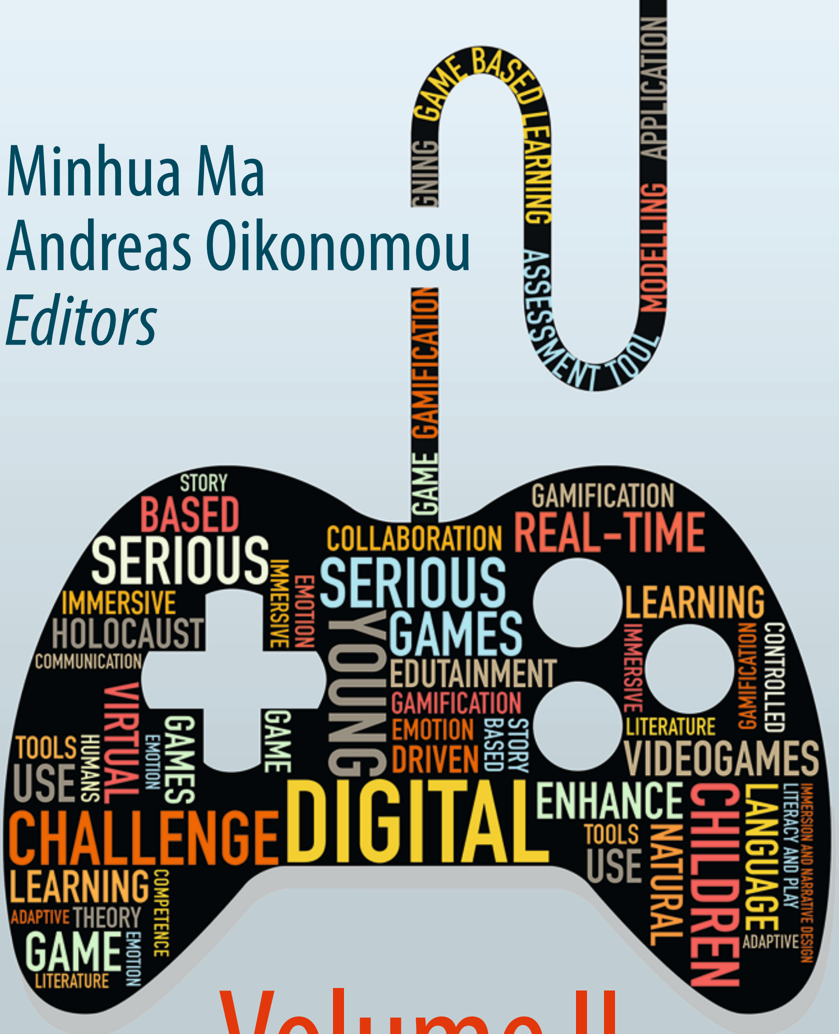
*Editors*




# Volume II

# Serious Games and Edutainment Applications

Springer

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Minhua Ma • Andreas Oikonomou
Editors

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# Foreword

When Eunice (the first editor of the book, a.k.a. Minhua Ma), Lakhmi and myself published the first volume of this book back in December 2011, we would not have perhaps predicted the direction of technological progress in the fields of games, serious games and edutainment applications, both in terms of hardware and software. Researchers, designers and even students now have wide access to effective virtual reality (VR) headsets; accurate, responsive, VR interaction control systems; portable augmented reality solutions like the Microsoft HoloLens; and the development software to support them.

This comes on top of what would be considered expected progress in areas such as graphics and general processing performance; faster, larger and cheaper memory; wider, brighter, higher-definition and even "bendable" displays; and so on.

In 2011, I remember questioning the title of the first volume and the word "edutainment" in particular. It was a term not widely used at the time, and I wondered whether new terminology was even necessary to describe the kind of research our book sought to highlight. Since then, edutainment has become fairly common both in industry and academia and is perhaps considered to be the obvious description of the kind of work it describes. After all, it means what it says, education through entertainment.

However, education in the past was not always an entertaining matter. Despite humanity's advances in methods and means of communication, we still have a lot to learn from observing how nature works, certainly in many fields but particularly so in matters relating to the transfer of information and building of skills amongst living beings, both human and animals. Take survival training for example, a skill as important for life as life itself for which one can expect evolution to have produced both efficient and effective ways of teaching and training the next generations. If one looks closely, a good part of it involves fun, games and play. Skill building and knowledge acquisition are a natural outcome of those activities.

Our first book looked into theories and reviews of serious games and edutainment applications. It also looked at custom-made games and case studies, the use of commercial off-the-shelf (COTS) games for educational purposes, social impact of games and the concept of gamification.

We wanted to benefit a wide range of people through that effort, academics, researchers, graduates and undergraduates in the fields of computer games and education, educators who wished to use games technologies in their teaching, game designers and developers, game publishers and entrepreneurs in the games industry.

For academics, it would serve as a good collection of related articles to facilitate a broad understanding of the subject and as such become one of the handbooks of choice to help select, plan and carry out teaching using commercial or custom-made games.

Professional game designers and developers adapting off-the-shelf virtual environment for teaching and learning purposes on the other hand would also find some interesting examples of using COTS games in educational settings and guidelines on choosing suitable games for the classroom.

Five years have passed since and this second book has a very similar mission, to classify and present advances in the area of serious games and edutainment. Readers will find the work presented here falling broadly under ten distinct categories, serious games and emotion, music-related edutainment, medical education and training, game-based learning, applications targeted towards children, serious games for serious purposes, gamification, assessment of the effectiveness of serious games, narrative design and methodological research in edutainment design.

In the first section, we will explore work that aims to utilise emotions as an active component of edutainment interactions. Games for music education will present two examples of how edutainment has been used to teach music. Medical education and training will present a number of research projects including works utilising virtual reality, haptic technologies, stereoscopic 3D display, etc.

The game-based learning section will present case studies for applications varying from chemistry to history education, whilst edutainment for children will explore case studies for children of varying needs and cultures.

Serious games for serious purposes will take us through case studies dealing with subjects such as the communication of culture and history followed by works in gamification theory and practice.

The effectiveness of serious games and edutainment applications is where we turn our attention to work relating to the assessment of the effectiveness of serious games. Finally, we will look at advances in narrative design and methodological approaches in edutainment design.

We hope that you will find the second volume as useful as the previous one. Who knows what the future of games, serious games and edutainment technologies and design approaches will be in the next 5 years, but if it is anything as exciting as what we have seen since the last volume of this book, we can hardly wait!

Nottingham Trent University, Nottingham, UK Andreas Oikonomou
October 2016

# Acknowledgements

I would like to acknowledge the help of all the people involved in this edited collection of *Serious Games and Edutainment Applications* (the second volume) and, more specifically, the authors and reviewers that took part in the review process. Without their support, this book would not have become a reality.

First and foremost, I would like to thank each one of the authors for their contributions. Our sincere gratitude goes to the chapter's authors who contributed their time and expertise to this book. They have not only written the state-of-the-art development of the subject matter but have done so with a sense of dedication, professionalism and enthusiasm that has made the job of editor much easier. I am proud of the work that we have assembled together.

Second, I wish to acknowledge the valuable contributions of the peer reviewers regarding the improvement of quality, coherence and content presentation of chapters. They worked to extremely tight deadlines and ensured a quick turnaround of reviews. I would like to thank Lakhmi Jain from the University of Canberra, Ioannis Parask from the University of Greenwich, Carlo Fabricatore from the University of Huddersfield, Gavin Sim from the University of Central Lancashire, Walt Scacchi from the University of California at Irvine, Stephen Tang from Liverpool John Moores University and Bob-Antoine Jerry Menelas from the University of Quebec at Chicoutimi. I appreciate their insightful and erudite review reports, which helped authors to improve their work and strengthen key sections of the book, and special thanks to coeditor Andreas Oikonomou from Nottingham Trent University and my PhD student Yeshwanth Pulijala at the University of Huddersfield.

Personal thanks go to the three most important people in my life: my daughters Brenda and Dory and my husband Jinbiao Sheng for their love and encouragement.

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17 October 2016

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Professor Ma is the editor-in-chief responsible for the serious games section of the Elsevier journal *Entertainment Computing*. She is the founding chair of the annual Conference on Serious Games Development and Applications, now called the Joint Conference on Serious Games (JCSG), which has been held in Derby (2010), Lisbon (2011), Bremen (2012), Trondheim (2013), Berlin (2014), Huddersfield (2015) and Brisbane (2016) and will be in Valencia in 2017. She gave a number of keynotes at the Jury Symposium Visual Evidence 2010, Anatomical Society Meeting 2012, CultureTech 2013, International Workshop on Waiting for Artificial Intelligence 2013, UK-US Serious Games for Health Workshop 2016, etc. Professor Ma was an expert judge for the International Loebner Prize Contest in Artificial Intelligence (the Turing test) to find the world's best conversational chatbot computer programme. She has been supervising 19 PhD students (4 completed) in games technologies and computer science. With her team, she has been developing serious games for healthcare and education with broad impact in creative technology and its applications in healthcare and education.

**Dr. Andreas Oikonomou** is a senior lecturer at Nottingham Trent University, UK, where he teaches computer science, human-computer interaction design and project management. He has previously taught computer science and games development at Derby and Coventry Universities as well as City College Coventry in the UK. Dr. Oikonomou has also worked in the software development industry as a technical project manager, quality assurance manager and studio head for the University of Derby's commercial games development studio where he successfully oversaw projects for clients such as the BBC. His current research interests include applied research projects in serious games, interactive technologies, biomedical computing and artificial intelligence.

# Part I
# Serious Games and Emotion

# Chapter 1
# Rising to the Challenge: An Emotion-Driven Approach Toward Adaptive Serious Games

**Claudia Schrader, Julia Brich, Julian Frommel, Valentin Riemer, and Katja Rogers**

**Abstract** Serious games are steadily becoming a powerful tool for educational purposes as their challenging characteristics are suggested to make them particularly appealing to learn with. This challenging nature, however, comes at a price, namely, the need to maintain the optimal balance according to players' emotional experiences. By focusing on players' emotions as main player characteristic considered to be important for learning processes and performance, this chapter surveys empirical research and current game development that contributes to an emotion-adaptive framework for games. The goal of this chapter is to clarify the importance of continuously adjusting game characteristics to players' emotional states. As the interaction between game characteristics and players' emotions highlights the need for continuously assessing at what point gameplay becomes more or less positively or negatively affected, methods for emotion recognition are presented. A summary of adaptable game design elements as well as implementation methods for adaptivity are provided.

**Keywords** Adaptivity • Adaptive games • Emotion recognition • Serious games • Procedural content generation

## 1.1 Introduction

The ongoing technical development and the use of serious games for teaching are accompanied by the question of how serious games can be designed to realize their assumed potential to foster learning processes and performance. Serious games

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are defined as systems that are assumed to "(. . . ) create engaging and immersive learning experiences for delivering specified learning goals, outcomes and experiences through the use of characteristics of video and computer games" (de Freitas 2006, p. 9). Game designers propose that key characteristics such as multiple representations, the ability to interact in real time with game objects, and the competitive nature of games tap into the full potential to offer challenging and joyful learning experiences and improve learning and performance. Thus, in the past decades, a significant amount of time and money has been invested to develop serious games, which are used for many application areas including regular and higher education as well as on-the-job training, for example, in the context of military or medicine.

Nevertheless, ambiguous results of the learning effectiveness of serious games demonstrated by previous research (Connolly et al. 2012; Wouters et al. 2013) have directed research and game development toward *adaptive gaming*. Adaptive gaming is based on research that investigates a more in-depth understanding of players' performance as a function of distinct game features and player characteristics and their interaction. The awareness of game and player characteristics has been mainly driven by strong empirical support, which demonstrates that the interaction of both affects game behavior and learning processes (e.g., Hamari et al. 2016; Schrader and Nett 2016; Shute et al. 2015). The obvious implication of this research is to maximize performance by providing adaptive game characteristics to affect players. Thus, game designers have departed from the traditional treatment of players as mostly passive receptors to a more player-personalized and data-driven approach by using player modeling techniques and adaptive game technologies for tailoring a game to player characteristics.

The realization of adaptive design in serious games ranges from a macro-adaptive approach to a micro-adaptive approach (Lee and Park 2008). A macro-adaptive approach, based on aptitude–treatment–interaction research (Cronbach and Snow 1977), provides a certain game version from a set of predefined game settings according to models of player stereotypes including player' previous knowledge and skills. Fewer examples exist for micro-adaptive approaches, which aim to auto-dynamically adapt game design elements to the needs of players and their changing characteristics just in time during gameplay.

Although all promising, the given examples demonstrate that there is a diverse understanding in terms of adaptivity. Up to now, critical issues include whether to stereotypically or automatically adapt which kind of game characteristics to which player characteristics. We will pick up these issues in this chapter by presenting players' emotions as a source of adaptivity. Game researchers and designers have recently recognized the importance of emotions since gameplay experience consists of a wide range of emotional reactions both positive and negative. Thus, we will discuss the purpose of adapting serious games to emotions to suggest them as a key variable for learning processes and performance.

## 1.2 Definition

There are many definitions of adaptivity as the term is used in a variety of domains engaging in human–computer interaction such as software engineering, ubiquitous computing, and artificial intelligence, as well as education and psychology. Within these domains, the term is applied for various forms and settings such as operating systems, networks, robotics, or multimedia learning systems (Bruni et al. 2012; Raibulet 2008) but also has a long history in traditional, non-virtual (educational) contexts (Corno and Snow 1986; Cronbach 1957; Dewey 1902/1964; Thorndike 1911).

From the perspective of **software engineering**, adaptivity focuses on the improvement of software to foster the quality of the interaction with the user. Here, adaptivity is defined as a system's ability to modify internal mechanics, content, and representation (Åström and Wittenmark 1995; Bendel and Hauske 2004; Kaukoranta et al. 2003; Raibulet 2008; Raibulet and Masciadri 2009; Smith et al. 2011). **Ubiquitous computing** similarly deals with enhancing human–computer interaction; the aim thereby is to support users in their everyday tasks by inferring intentions and adapting the system based on the current context (Banavar and Bernstein 2002). The perspective of **artificial intelligence** views adaptivity as a dynamic reconfiguration of a system's behavior by requiring and storing current user information in internal models to appropriately respond to it in future situations (Wenger 2014, p. 16). In games, for example, this is realized by providing a gameplay experience that forces players to continuously search for new strategies to defeat the game (Manslow 2002). For an individualized gameplay experience, player state and interaction are measured and analyzed on the basis of existing or emerging player models; game elements are then created to fit each player–context combination specifically (Lopes and Bidarra 2011a; Yannakakis and Togelius 2011). The alteration of any form of learning intervention based on user characteristics is the main understanding of adaptivity in the context of **traditional curricula or multimedia learning systems** such as serious games (e.g., Vandewaetere and Clarebout 2013; Vandewaetere et al. 2011). Here, the purpose of adaptivity is strongly connected to the intervention's learning effectiveness (Corno and Snow 1986).

Summarizing the different understandings of adaptivity and what it should comprise, adaptivity can overall be defined by three recurring conditions including (1) changes in the systems' mechanics and representations that are visible in the systems' behavior to (2) better tune into the needs and desires of users in order to (3) optimize the interaction between the system and the user to achieve a certain quality.

Applying these fundamental conditions to serious games, adaptivity can be defined as *a player-centered approach by adjusting games' mechanics and representational modes to suit games' responsiveness to player characteristics with the purpose of improving in-game behavior, learning processes, and performance.*

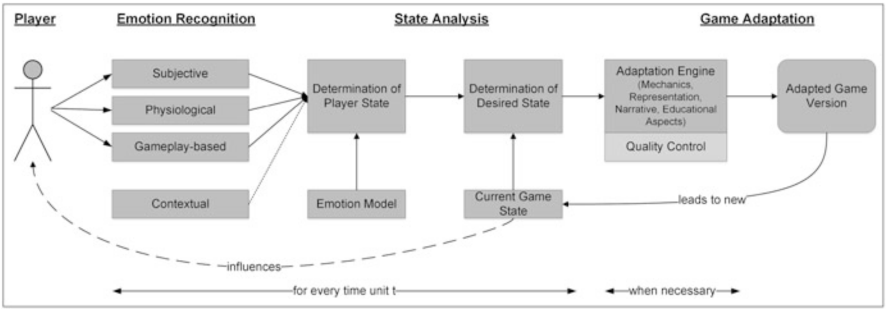


**Fig. 1.1** Model of emotion-driven adaptivity for games

From this brief review on adaptivity taking into account the different perspectives, it is highlighted that the interaction between game and player characteristics is crucial for adaptive games. The goal of this chapter is to give an overview of the relations of underlying factors that are included in current frameworks for developing adaptive game systems (Nguyen and Do 2008; Shute and Zapata-Rivera 2012; Yannakakis and Togelius 2011). As proposed in our approach presented in Fig. 1.1, the importance of emotions is discussed as a source of adaptivity. Detecting and analyzing players' emotions in order to construct player models is a challenging task as emotions can dynamically change via interaction with the game characteristics during gameplay. Measurement methods for recognizing these changes will be discussed. Examples of adaptivity in games including not only games' mechanics and representations but also narration and educational elements for tailoring serious games based on emotions will be further presented, building on current research and development derived from the field of affective computing. As we posit a player-centered automatic adaptation approach, all factors are dynamically linked to one another, as represented by the feedback loops in Fig. 1.1.

## 1.3 Emotions as Player-Centered Source of Adaptivity

General agreement exists that learning through gaming is more efficient when adapting games to individual player characteristics in order to create a player model. A wide range of player characteristics exists on which the player modeling process can be based for subsequent adaptation. Aptitude variables, e.g., differences in the type of player (Magerko et al. 2008; Orji et al. 2014), or knowledge, skills, and abilities regarding the domain-related content and gameplay, all provide an input for stereotype player modeling (Brusilovsky and Millán 2007), resulting in a micro-adaptive approach. Feature-based modeling (Brusilovsky and Millán 2007), in contrast, is more fine grained by considering player characteristics as variables that arise during gameplay and that are triggered by specific game characteristics.

This chapter focuses on players' emotions as one key aspect of this feature-based modeling approach, which represents a real-time micro-adaption of game characteristics on a more individual basis. Emotions are seen as a continuously progressing player characteristic that interacts with the game design and that changes during the time of gameplay. Emotions are overall defined as multimodal responses to a situation (Frijda 1988) causing not only changes in subjective feeling but also in physiological activity such as heart rate or blood pressure, and in diverse expressions, such as facial or whole-body behavior (Ekman et al. 1983). Emotions can be ordered solely by their discrete nature including basic (e.g., anger and happiness) and complex emotions (e.g., shame and pride), or they can be ordered according to their valence (positive–negative) and activation (activating–deactivating) (Russell 1980; Tellegen et al. 1999). The purpose of adapting games to emotions lies in the importance of emotions both positive and negative, as well as activating and deactivating ones, as key player characteristics for task engagement and persistence. Further, there is theoretical and empirical evidence in the field of educational psychology that emotions determine learning processes such as directing attention (Meinhardt and Pekrun 2003), and as a result performance (e.g., Efklides and Volet 2005; Kort et al. 2001; Linnenbrink 2006; Schutz and Pekrun 2007).

The challenge of improving engagement and learning through emotion-sensitive adaptive games depends on research recognizing emotions, their interaction with learning processes and performance, as well as their interplay with other player characteristics and game features. Accurately measuring emotions is one prerequisite for generating an appropriate player model and adaptive game strategies to respond to emotions, which, for example, might be harmful for learning. Three different perspectives in current game research—investigating emotions either as a main or additional research focus—can be distinguished: research on (1) emotions as an outcome of games in general, (2) differences in emotions by comparing games with other media, and (3) differences in emotions comparing different game elements, all with the main purpose of evaluating and improving game implementations.

The first research perspective on games in general shows that the improvement of positive emotions is one of the main reasons why children and juveniles play games in their leisure time (e.g., Hainey et al. 2013; Russoniello et al. 2009; Sobkin and Evstigneeva 2004). It has been suggested that strongly connecting games to positive emotions leads to the development of knowledge and skills by using serious games (Anolli et al. 2010). While a number of studies (e.g., Barab et al. 2005; Ricci et al. 1996) within the second perspective find that learning with serious games can result indeed in greater enjoyment and better learning outcomes compared to traditional media, nonsignificant outcomes or negative effects have been reported in other studies (Rodrigo and Baker 2011; Wong et al. 2007). These disparate findings have yielded a third perspective on research that investigates whether and how specific game characteristics trigger emotions. An example is the effect of gameplay difficulty that leads to different levels of player challenge. Difficulty can be operationalized, for example, in terms of variations in pace of gameplay or number of items that have to be handled at the same time. The study of van Lankveld et al. (2010) demonstrates that if the gameplay challenge due to the difficulty is suboptimal, i.e., too low or too high, players become bored or frustrated. This can critically affect players' task engagement and persistence (van Lankveld et al. 2010). However, gameplay challenge leading to poor game performance does not necessarily lead to negative emotions (Gilleade and Dix 2004; Johnson et al. 2015) and does not directly cause lower engagement. Research that focuses on trends and changes in emotional experience during gameplay demonstrates that while a high level of difficulty, e.g., in terms of navigation requirements (Klimmt et al. 2007), in content (Schrader and Nett 2016) or in pace (Tijs et al. 2008) frustrates players at the beginning of a game, emotions do change during gameplay with increased practice and gameplay experience leading to lower frustration. These findings make clear that the relation between emotions and game characteristics is complex and at the same time influenced by other player characteristics such as increased gameplay experience and practice, resulting in a variety of in-game behaviors and performances.

## 1.4 Emotion Recognition: Assessing the Player's State

For our approach there is the methodological issue of how to recognize emotions in order to adapt game characteristics. Instead of retrospectively measuring players' emotions as outcome of a gaming session as done in various studies (Barab et al. 2005; Ricci et al. 1996; Wong et al. 2007), recognizing emotions with assessment embedded in games is required in order to understand how and at which point there is a need to adapt. To our opinion, this will meet the understanding of adaptivity: delivering the right content, to the right person, at the right time in the most appropriate way (National Association of State Boards of Education 2001). Thus, in this section, we introduce the most frequently examined methods of recognizing emotions that have been the focus of research in the domain of human–computer interaction (Cowie et al. 2001) and are an important part of affective computing (Picard 1997).

### *1.4.1 Self-Reports of Emotional Experience*

The most direct way to learn about players' emotional experience is asking them by using self-reports (Yannakakis and Togelius 2011). Self-reported data for emotion recognition can be extracted using a **free-response** form or from **forced** self-reports including scale ratings and preferences (Yannakakis and Paiva 2014). Examining emotions from free-form responses suffers from the limitation that they are quite difficult to analyze; yet they can be quite expressive. Forced self-reports can be subdivided into rating, e.g., Likert scales, and preference measures, i.e., where the user can choose one of two options. While ratings have the issue that it is often quite difficult to assess one's own emotion on a scale, they are easy to administer and analyze. Self-reported preference on the other hand is easier to self-assess for the players but can lead to longer studies as more comparisons are necessary. For an extensive discussion on both types of forced self-reports, see Yannakakis and Hallam (2011).

Generally, the use of self-reported data in research is accompanied by some inherent limitations including the issues of retrospective accuracy, trustworthiness of the user (particularly for remote questionnaires), and randomness (i.e., guessing behavior) as well as alexithymia (i.e., the missing awareness of one's own emotions) (Mauss and Robinson 2009; Westera 2014). Another and more important limitation in terms of games is the interruption of gameplay (Becker and Parker 2011; Pagulayan et al. 2002). For dynamically recognizing emotions during gameplay, it is necessary to administer self-reports during the game or between game sections. A possible solution to this limitation is integrating self-reports more unobtrusively into game environments as suggested by Shute (2011). This approach has been shown to mitigate the effects of interruption on players' presence (Frommel et al. 2015; Mountain 2010).

### *1.4.2 Physiological Responses*

In overcoming the disadvantages of self-reports mentioned in the previous section, researchers have sought ways to infer emotions from other data such as from physiological responses (Cacioppo et al. 2000; Larsen et al. 2010). Data about physiological responses can be collected from the autonomous nervous system (e.g., cardiovascular signals, electrodermal activity), the somatic nervous system (e.g., facial and whole-body behavior), and the central nervous system (brain activity); all have received wide attention in psychology research as well as in human–computer interaction research. In the following, we introduce the most frequently examined physiological responses in terms of cardiovascular signals, electrodermal activity, as well as facial and whole-body behavior and highlight some of the findings regarding emotion recognition in games.

In the field of psychophysiology, **cardiovascular signals** such as heart rate, heart rate variability, and blood volume pressure have been related to the experience of emotions (Larsen et al. 2010). In game research, significant differences in heart rate are reported for slow vs. fast game conditions in an adapted version of *Pacman* (Tijs et al. 2008), for different levels of game difficulty in a *Tetris* game (Chanel et al. 2011), and for specific game phases eliciting different levels of activation in the arcade platform game *Super Monkey Ball* (Ravaja et al. 2006). By investigating the relation of physiological responses and emotions, Drachen et al. (2010) show that an increase in heart rate during playing an ego-shooter game was associated with negative self-reported emotions, whereas a decrease correlated with positive ones. More recently, Vachiratamporn et al. (2015) analyzed heart rate to differentiate between a neutral affective state and different levels of fear in a horror game.

Their findings correspond to the findings of Cacioppo et al. (2000), who report that negative emotions are accompanied by higher autonomic activity compared to positive emotions. Conversely, Mandryk et al. (2006), using a sports game, report no significant correlations between heart rate and self-reported emotions. Likewise, Tognetti et al. (2010) found no relation between heart rate and self-reported enjoyment in a car racing game.

**Electrodermal activity (EDA)**, often referred to as skin conductance or galvanic skin response, is generally considered a valid measure of physiological activation (Lang et al. 1993), whereas findings regarding emotional valence are inconsistent (Larsen et al. 2010). In game studies, reports of increased levels of EDA are associated with higher levels of experienced enjoyment (Mandryk et al. 2006; Tognetti et al. 2010). On the other hand, Drachen et al. (2010) found a positive relationship between high levels of EDA and frustration. Similar to heart rate, EDA has proven its discriminative power for different game levels (Chanel et al. 2011; Tijs et al. 2008) and specific game events (Ravaja et al. 2006).

The analysis of **facial behavior** can be divided into approaches relying on electromyography (EMG) data and those who apply visual methods to assess facial behavior. In taking the former approach, Tijs et al. (2008) show that in their Pacman game, increased activity of the zygomatic muscle, which is indicative for smiling, corresponds to higher levels of self-reported positive emotions. Hazlett (2006) reports similar results from an EMG study involving a car racing game. During the gaming session, zygomatic activity was observed more frequently when positive game events occurred (e.g., passing other cars) compared to negative game events (e.g., being passed by another car). Additionally, increased activity of the corrugator muscle, which indicates frowning, was more frequently observed during negative game events. In contradiction to the results of Hazlett, Ravaja et al. (2006) find that EMG data does not always correspond to game events in the expected direction. In *Super Monkey Ball*, some presumably negative events (e.g., falling off an edge) were associated with an increase in zygomatic activity, which would hint to an increase in positive emotional experiences.

In contrast to recognizing emotions via facial behavior using EMG data, the detection of facial behavior based on visual data has been used to infer users' emotions predominately in learning settings involving intelligent tutoring systems (Azevedo et al. 2009; D'Mello and Graesser 2012; Harley et al. 2013). Recently, Wiklund et al. (2015) used the *FaceReader* software to compare playing an educational game to playing an entertainment game. While they did not assess emotions other than by the facial expression software, the group playing the learning game showed more negative facial expressions than the group playing the entertainment game. While emotion recognition based on EMG data has the advantage that plugging is robust to different lighting conditions compared to emotion recognition based on visual data. On the other hand, however, the latter approach is less invasive.

**Whole-body behavior**, i.e., postures and movements that involve parts of the body other than the face, is reported to allow inferences about a variety of emotional states (see Kleinsmith and Bianchi-Berthouze (2013) for an overview). In game research, Bianchi-Berthouze et al. (2006) visually observed differences in the frequency of shifts in the seating position for two different desktop games. Participants who played a highly immersive ego-shooter showed less shifts than those who played an unspecified low-immersive “mouse-clicking” game. The authors attribute these differences in body behavior to states of engagement and boredom, respectively (Bianchi-Berthouze 2013). Examining head movements based on video analysis, Shaker et al. (2011) show that high frequency and velocity of head movements was indicative of failing in a *Super Mario Bros.* game. Taking a different approach, Kleinsmith et al. (2011) used a full body exoskeleton to collect body movements during playing a Wii tennis game. They identified several low-level features (e.g., rotation of the shoulder, bending of the torso) based on which players’ arousal and valence could be differentiated.

### *1.4.3 Gameplay-Based Emotion Recognition*

Besides trying to infer emotional reactions from players’ physiological responses during gameplay, another important objective method for emotion recognition is evaluating the current state of the interaction of the player with the game, i.e., all information of what the player does in-game. This state can comprise all kinds of different game factors like the game features the player uses most, the game events that happen (e.g., “the player dies,” Brich et al. 2015), or even the player’s behavior in dialogs with non-player characters (Mountain 2010).

In terms of game features the player uses most (Hastings et al. 2009), for example, generated weapons in a space shooter game based upon weapon usage. The authors suggest that players generate and use the weapons they liked best, which implies the assumption that the weapons that players use most generate more enjoyment for them. Pedersen et al. (2010) used game events such as game completion time and information about the player’s death to build models of player experience for a platformer game. They generated levels for an adaptation of *Super Mario Bros.* and were quite successful in predicting players’ emotions. In further research (see Sect. 1.4.2 as well as Ravaja et al. 2005, 2008), manipulating specific game events has been used to influence physiological responses that have been shown to have the capability to measure emotions, for example, such as EEG measurements (Wu et al. 2010). While it is suggested that the measured physiological reactions depend on specific game events, findings of other studies (McMahan et al. 2015) demonstrate that these are dependent on the success, i.e., winning or losing a game.

Players’ in-game behavior, nonetheless, has the advantage of being very unobtrusive and has been shown to be an important additional source of information for determining emotions and, further, to assess the fitness of generated game content (Hastings et al. 2009; Yannakakis and Togelius 2011).

Concluding this section, the currently employed methods to recognize emotions during gameplay seem to be a promising approach not only to infer players’ emotional valence but might also help to detect discrete emotions. However, the review of findings has also demonstrated that recognizing players' current emotions is a nontrivial question as none of the presented approaches are perfected yet, with each having disadvantages. While self-reports are a direct and cheap method to detect nonbasic discrete emotions, they suffer from limitations such as individual differences in social desirability as well as alexithymia, and interrupt gameplay. Measuring physiological activities and linking these to emotions, in contrast, enables a continuous measurement and is unbiased by personal characteristics. Physiological measurements, however, are frequently ambiguous. They can detect only some, if any, discrete emotions and are quite intrusive, costly methods. Gameplay-based emotion recognition is generally very unobtrusive but requires assumptions about the mapping of in-game data and emotions and requires a lot of training data to produce suitable models. As research using each of these methods in isolation, further, showed inconsistent findings, we apply an multimodal approach of **sensor fusion** from cardiovascular, face, body, gameplay interactions and players' contextual surroundings to achieve more accurate results in emotion recognition.

## 1.5 Implementation of Emotion-Driven Adaptivity in Games

Independent from the choice of specific methods for the recognition of players' emotions, the question that arises is how to leverage the detected information as part of the design of adaptive games. A wide range of game characteristics including the parameters of game mechanics, representational aspects, narrative, and educational aspects can be generated and adapted based on and in order to influence players' emotional experiences, as assessed by one or a combination of the methods discussed in the previous section. However, the field has not yet reached a consensus regarding methods for the generation of player models or the choice of game features for adaptation (Andersen 2012). Based on the results of expert interviews, Shute and Zapata-Rivera (2012) list a number of methods to build player models in adaptive environments, among them machine learning, probability and decision theory, or constraint computing. They also discuss methods for adaptivity in terms of their representational modes (i.e., offering alternative representations with equivalent meaning), as well as degrees and combinations of manual and procedural approaches toward adaptivity. The many technical approaches are discussed from a variety of perspectives in current literature (Lopes and Bidarra 2011a). Other approaches toward providing adaptivity focus on a more contextual level: Regarding adaptivity in learning environments, Lee and Park (2008) describe two instructional approaches for adaptivity, namely, differentiating between adaptation of macro-level or microlevel elements.

However, regardless of the favored approach, adaptation is generally viewed as an important method for achieving widely appealing and re-playable entertainment games, as well as—and perhaps particularly—for achieving the primary goal of serious games, i.e., conveying knowledge and skills. Thus, recent research in adaptivity has begun to consider a broad set of game characteristics and new avenues of research are currently being addressed. As for the intended effect of adaptivity, entertainment games usually focus on maximizing fun to keep players engaged. With regard to learning, a more nuanced approach has to be taken to strike a compromise between accommodating player preferences and supporting the intended educational goal. Information relating to this can be added to the aforementioned player model which will function as the basis for adaptation in our analysis.

In the following, we first provide an overview of specific game elements which can be and have been adapted, then discuss methods and approaches toward implementing adaptive games, and finally describe the potential impact of adaptivity on players' emotions in the context of serious games.

### *1.5.1 Adaptable Game Elements*

To achieve emotion-driven adaptivity via the adaptation of specific game elements, several areas can be contemplated. Regarding the design space of potentially adaptable game elements, the developer's imagination may well pose the only limit. With regard to game mechanics, elements like game difficulty, external performance rewards, and social gameplay mechanics can be targeted. Considering representational aspects, world layout, character presentation, shape design and coloring, audio, and degree of interactivity are of interest. Finally, narrative and educational aspects—which draw from both mechanics and presentation— also add nuances of their own.

As mentioned in Sect. 1.3, the area in which games are most commonly adapted and provide largely functional adaptivity consists of dynamic **difficulty** adjustment. For example, *Max Payne* is one of many games to offer aim assistance in first-person shooters. In *Mario Kart Wii*, the distribution of helpful items adapts to the player's race position so that weaker players will receive better items and vice versa. Similarly, *Pro Evolution Soccer 08* adapts to poor player performance, albeit by improving the enemy team to specifically target the player's weaknesses. *Left 4 Dead 2* adapts the game world layout's difficulty based on player skill, for example, by influencing item spawning, route mapping, and the activation of enemy hordes. The newly released *Epistory*—an adventure game developed to enhance typing skills—is an example for the incorporation of dynamic difficulty within a serious game. Unfortunately, players sometimes dislike adaptivity when this is implemented in a too obvious manner, as this decreases the perceived value of succeeding in the game (Yannakakis and Togelius 2011). The game elements involving "luck" may therefore be perhaps particularly well suited for secret adaptation. For example, the game might increase the likelihood of a player to achieve critical hits on enemies, a large amount of loot being carried by defeated enemies, and how often helpful items are spawned near players. Further, the enemy AI can choose less-optimal actions, or the player's task progression can be adjusted to supply easier or more difficult missions.

The adaptation of **external performance rewards** such as achievements or badges that are awarded outside the actual gameplay may also have a strong impact on a player's learning progress. For example, the rewards can be generated in a goal-oriented manner, i.e., to teach specific skills. Adaptive achievements could further be used to promote the exploration of specific content or teach game mechanics previously overlooked or avoided by the player. One achievement in *Epistory* reads "Diamond in the rough: Type 100 characters without a mistake" and thus encourages the player to focus their attention on precision rather than speed. This type of game mechanics can thus be designed to especially reward behavior benefiting the educational task. Achievements and the like might also be a viable method to foster engagement by accommodating player preferences (e.g., rewarding the player for exploration rather than defeating monsters, if this is more to their liking).

Another common aspect of modern games consists of **social gameplay** elements. These include public leaderboards, chat functionality, and the use of social media to recommend the game to friends. These elements can of course also be adapted, for example, by enabling or disabling these functionalities based on player preference. Players that shy away from public challenge or attention may prefer the game not to include their game achievements in public high-score lists, whereas other players might lose interest without this game feature. This also holds true for enabling the player to compete in challenges with their friends. A good example for these kinds of challenges comes from the gamified fitness application *Fitbit* where players can, for example, engage in "Daily Showdown"—a challenge to determine who can walk the most steps in one day. While this feature may be highly motivating for some, others might prefer to avoid the direct confrontation that comes with this feature. In a similar vein, it can be beneficial to offer task completion both in the competitive and collaborative paradigm. The latter allows for players to combine their efforts or even help weaker teammates to achieve new goals.

As a first example from the area of adaptable representation, a game's underlying **game world paradigm**—open vs. linear game worlds—and **game world layout** can be examined. An open game world paradigm concerns games that allow players to explore in many directions, whereas a linear game world paradigm restricts this exploration such as is done in a side-scrolling game. Open game worlds (e.g., *Skyrim*) provide a greater potential for the element of fantasy (Malone 1981; Malone and Lepper 1987) and may thus better support autonomy (which is crucial for intrinsic motivation according to self-determination theory Ryan and Deci 2000). While not focused on providing adaptivity, the freshly released *No Man's Sky*, for example, has received a great deal of press attention even before its release (Khatchadourian 2015; Parkin 2015; Walker 2016), for generating entire solar systems including planet life on a pioneering scale for players to explore freely. Linear worlds however may be better suited for players that dislike extensive exploration or lack the necessary orientation skills to find their way around an open world. Our review was however not able to find any games that adapt their game world paradigm, possibly due to the fundamental nature of such change. Open vs. linear game world layouts, however, distinguish games by the degree of complexity of their level or space layouts, much as in the previously mentioned example of *Left*

*4 Dead*, where the levels are presented in a more linear, simplified manner for less experienced players and more complex and circuitous for players requiring greater challenge.

The **characterization of non-player characters** (so-called NPCs) is also important for adaptive games. Some players might consider an NPC's behavior too confrontational or serious and would appreciate a more helpful and friendly NPC. Other players might greatly prefer a more distant NPC and consider the friendly NPC too cloying. How players react to dynamic shifts in character during a single game session has not yet been investigated to our knowledge. Other NPC attributes, such as appearance and backstory, can also potentially become adaptable elements, as well as dialog content, tone, and strategies.

With regard to **shape design and coloring**, Plass et al. (2014) state that warm colors and round shapes are conducive to positive emotion and learning; in games, this could be capitalized on for NPCs, message presentation, or even levels as a whole.

Furthermore, **audio**—in its game manifestations as background music, voice-overs, and sound effects—has been shown to have a significant effect on the player's immersion, for instance, through the use of dynamic music, i.e., music that adapts to game events (Gasselseder 2014b). Voice-overs have been shown to correlate with higher player engagement (Byun and Loh 2015), and sound effects in particular have an important function in providing feedback, thus increasing games' usability. Regarding emotions, music has been shown to have a strong effect in evoking specific affective states, e.g., Koelsch (2010), Pozderac-Chenevey (2014) and Zentner et al. (2008). The potential of audio for distracting players may however have a particularly adverse effect on the additional educational goals of serious games. As of yet, there is little research evaluating this in a methodological manner in the context of games—considering the fact that visuals also have an effect on music perception (Gasselseder 2014a), this field of research presents several directions with unanswered questions for future investigation on the effect of games on players' emotions.

Another representational aspect concerns the degree of **interactivity**. Particularly with increasingly realistic gameplay graphics, some games provide very seamless transitions between gameplay and cutscenes (e.g., *Watch Dogs* or *Everybody's Gone to the Rapture*). Moreover, the domains of games and movies increasingly overlap, providing similar quality and depth of narrative and audio (e.g., *Beyond: Two Souls*). Adaptation in this area may have to consider whether individual players prefer more or less interactivity in their games, as this preference can vary (Levy 2008).

The **narrative** of a game is particularly important for players to engage with the gaming experience. Adaptation of the narrative has become its own field of research. For example, in-game player decisions can be used as a basis for the selection of one of multiple possible narrative progressions (often defined through different story endings), as in *Beyond: Two Souls*, which offers more than 20 different endings based on whether various non-player characters (NPCs) survive. *Life Is Strange* provides only two different endings, but the narrative of NPC encounters and dialogs changes drastically based on the player's choices (e.g., deciding or refusing to help a specific NPC). In *Witcher 3: The Wild Hunt*, the player's decisions also have a significant impact on the narrative progression, e.g., through mission outcomes. An academic counterpart to these examples is *Façade* (Mateas and Stern 2003), a game designed to offer the player an interactive narrative via drama management and agents. With regard to player task progression, which is often closely intertwined with the game's narrative, the decision to adjust the style of tasks between more and less linear, as well as the distinction between main and side quests of varying complexity, duration, and influence on the main storyline, can further be adapted. The potential for adaptivity in narration was further explored by Roberts and Isbell (2008). Many games thus show a degree of adaptivity in narration, but it is often limited to a basic story tree through which the player can navigate in multiple but finite ways. Fully automatic narrative generation—that also guarantees engaging and coherent experiences, much as *No Man's Sky* is attempting for game worlds—is not yet possible. Regarding the order of learning content, a game's narrative and task progression could be adapted to teach specific skills embedded in the context of the game's storyline. The presentation of these tasks can also be further adapted regarding the **origin of tasks**. The player could prefer tasks assigned by NPCs (e.g., mentor or companion characters) or less social interaction via more anonymous task assignment (e.g., posted on an in-game bulletin board). The **medium** of this task offers another option for adaptation, e.g., via video message, letter, flashback, animation sequence, text/audio, and so on. Further, depending on the player's preference for narrative and background, they may respond better to either a quick or more elaborate delivery of the task. For example, the perfunctory "Go kill 10 lizards" may appeal to a different kind of player than "The lizards have invaded your game world; only you can save mankind, do so by defeating all 10 evil lizards!" Even given a preference for narrative and backstory in general, the degree to which players engage may differ significantly based on the story presentation. To mention a few variables, the presentation thereof can vary in length, complexity, detail, point of view, and mode or tone.

With regard to serious games, the abovementioned game elements allowing potential adaptation can be further extended to include **educational elements**. In particular, the elements used to uphold enjoyment in commercial games can be reused and further extended to increase learner motivation. Shute and Zapata-Rivera (2012) provide an overview of such potential educational elements for adaptation based on expert interviews, i.e., the instructional variables of a game. For example, they describe the adaptation of **feedback**, the **sequence** in which learning content is introduced, and **presentational aspects** of how the content is offered up to the player.

Finally, procedural generation has even focused on the generation of **games as a whole** (Nelson and Mateas 2007); game rules and mechanics, as well as their audiovisual implementation, are then generated by mapping thematic verb–noun concepts (e.g., *shooting* and *monsters* or *collecting* and *gems*) onto schematic game concepts that describe the player role (e.g., *Avoid*, *Shooter*, or *Acquire*), with an underlying database of stock images and models. This kind of adaptation is still in early stages; as of yet, its potential use for serious games remains unclear.

### 1.5.2 Current and Envisioned Implementation Methods

Generally, game adaptation can be classified by its degree of automation (without automation, semiautomatic, or fully automatic) or the time of adaptation (offline, online during loading screens, or fully online). Nonautomatic adaptation consists of static choices available for the player to trigger or choose from. For example, game variants with specific levels of difficulty can be created during development (without automation) and then presented to the player to choose from. A game franchise famous for its large set of difficulty settings is, for example, Blizzard's *Diablo*. Alternatively, these different game variants might afford more implicit player input, such as offering different scenes based on previous player choices. The system can then load one of several predesigned variants. These choices can also be triggered dynamically during the game—for example, the narrator's reactions to the player actions in *Bastion*. Any game's nonrandom response to interactive player input can be considered nonautomatic adaptation.

Using automation to some degree can immensely strengthen a game's replay value by affording a larger number of variants for the player to try out and also ideally increasing the likelihood that the produced variants will appeal to a wide range of players. This adaptation is sometimes implemented semiautomatically, i.e., it is intended as a support system for the designer rather than as a replacement. Game designers can thus formalize a basic draft of game variants, but parts of the variants are then developed and generated automatically by the system. This can occur in the form of development tools during the game's development process, e.g., the game designer formalizes the requirement for a forest at a certain location, while the individual trees are then generated automatically by the system environment. In other cases, the system might generate sample choices of game variants, and the game designers choose which adaptation should occur based on which player input. For example, the *Refraction* game was developed in this manner to provide adaptive difficulty levels (Andersen 2012; Andersen et al. 2013). Further online semiautomatic adaptation can still occur during gameplay, for example, to generate more details. This semiautomatic approach to automation is sometimes also described as a combination of manual and procedural generation for games, e.g., procedural sketching followed by manual refinement as described by Smelik et al. (2010), or the mixed-initiative design process by Smith et al. (2010). Interestingly, this mixed-initiative has even included the player in *LittleBigPlanet* (Dormans 2011). *Scribblenauts* could also be considered a mixed-initiative example, although the degree of player involvement is hard to quantify in comparison to explicit level editors, which are also increasingly common, e.g., *Super Mario Maker*.

Fully automatic adaptation requires no additional designer input, for example, to generate and expand the game world based on player actions during gameplay. Lopes and Bidarra (2011b) describe a framework where game designers specify information about what game content provides what kind of experience for what kind of player in the form of semantic gameplay descriptions. Afterwards, the generation system is able to generate levels fully automatically and adapt them during play to provide specific gameplay experiences. For example, players that exhibit exploration traits will increasingly be offered more areas to explore while players that like to improve their character will find more appropriate items in the next rooms of the building they are currently in. An example for a more serious game-oriented setting is given in the form of a driving simulator where realistic street situations are generated to fit the player's developing driving skills.

When discussing automation, the topic of content generation is often closely related. Only a few years ago, Yannakakis and Togelius (2011) described the process of content creation as still largely nonautomated, and despite the ongoing trend toward procedural content generation (PCG), this still appears generally true today. Prominent examples for PCG however include the immensely successful *Minecraft* and the newly released *No Man's Sky*. In *Minecraft*, the entire game world is created fully automatically before each playthrough, while *No Man's Sky* cleverly uses the travel time between planets to generate their flora and fauna.

Nevertheless, procedural content generation can be and has been implemented in a way that takes into account adaptive mechanisms as discussed above, i.e., offline adaptation as discussed by Lopes and Bidarra (2011a). Today, it is used mostly at very specific instances of games, e.g., to quickly create game objects in game world environments. Non-prototypical use of such generated content requires a high degree of variability and reliable quality from the underlying algorithm. In combination with adaptation, this is still rarely fulfilled through PCG approaches beyond focusing on singular aspects, even with design specifications from human game developers—at least in part because of the complex nature of games.

Regarding the implementation of procedural content generation—both with and without the additional feature of adaptation—its usage in commercial games represents a challenge for surveys due to the usual issue of little or no availability of or access to detailed information. However, games have been known to use PCG to some degree for several decades; *Rogue* and *Elite* are rather early examples from the 1980s, and *Diablo* and *Civilization* are well known for procedural and randomized map generation. *Minecraft* uses Perlin noise to generate its biome-specific terrains, and *Inside a Star-Filled Sky* procedurally generates the beats of its background music based on player and enemy movements. Furthermore, procedural generation was also used for animations and textures to bring the world and manifold creatures in *Spore* to life. Yet *No Man's Sky* is among the first to be actively promoted as touting a procedurally generated, infinite game world, with the difference being the seamless temporal pervasiveness of the game world, as opposed to the infinite generation of new, self-contained levels that are discarded after playthrough. While it is uncertain to what degree these games already include adaptive mechanisms, the advances in PCG technology also promise new possibilities for PCG in combination with adaptation in future research.

Academic projects have provided more readily available information on the subject of implementing adaptive games. One particularly interesting aspect is the trace-based framework by Andersen et al. (2013), which generates problem progressions for procedural tasks, to synthesize levels for learning games. Several researchers have used evolutionary algorithms for content generation. Evolutionary algorithms generate solution candidates for specific problems by evolving representative candidates (through combination or mutation) toward an increasingly higher fitness. This approach has proven particularly popular in the generation of 2D game levels. For instance, the fitness evaluation can be used to select for a specific degree of challenge (e.g., Sorenson and Pasquier 2010). The candidate representation for level generation is often based on grammars, as in the *Super Mario Bros* level generation by Shaker et al. (2012). This approach has also been used in puzzle generation by Shaker et al. (2013). Dormans describes the trade-off between different variants of grammars for generating levels; he further points out that it is crucial that levels not just feature technical validity, i.e., avoiding non-reachable areas, but also consider "enjoyable exploration" and accommodating the underlying narration (Dormans 2010). However, evolutionary algorithms have also been applied to structures other than grammars, neural networks too have been adapted, as described in a survey paper by Risi and Togelius (2014). For instance, they have been used to develop a player agent that can simulate gameplay of racing tracks to test generated game world environments (Togelius et al. 2007) or to predict the affective state of players in combination with automatic feature selection (Pedersen et al. 2010).

Grammars have also been used for 3D game world generation, e.g., cityscapes (Müller et al. 2006). Other approaches instead use a seed value and then apply various noise functions to generate a game environment. These can be further transformed via height maps and functions, in order to create specific patterns without the randomized terrain, e.g., paths or rooms. Other approaches are based on players' in-game history of behavior. For example, items may be generated upon review of the player's most and least frequently used game objects or features. Another paper by Smith et al. (2011) describes this approach in more detail, by means of a 2D platforming game that uses player actions as input parameters for its infinite level generation. They nevertheless emphasize the importance of human input to provide a nonrandom gameplay experience and transparency regarding the effect of player behavior on procedurally generated game elements. The generation of quests is discussed in further detail by Lopes and Bidarra (2011a); this field has used L-system grammars and planning systems, among other methods.

Further, an orthogonal approach toward adaptivity consists of in-game changes to the player model, as opposed to pre-generated modifications (e.g., generated while loading). This online adaptation approach is often used to adjust NPC behavior, for example, in order to present a suitable dialog strategy for interaction with the player. This research area overlaps strongly with traditional human–computer interaction and dialog systems. This kind of adaptation is often implemented via rule engines (Spronck et al. 2006) and state machines (Hartley and Mehdi 2009; Kazmi and Palmer 2010). However, Dormans suggested that generative grammars could also be used to grow levels based on player behavior, for example, to accommodate player preferences or ensure variety of game elements (Dormans 2010).

### 1.5.3 Application in Serious Games

In the previous paragraphs, we presented a broad overview over the established and potential approaches to adaptive games. The question that remains is how emotion-driven adaptivity can benefit the field of serious games. As presented in this chapter, there is general agreement on the notion that instructional tools increase in efficiency when content and medium are tailored to the recipient. Learners are however complex in nature and comprise a variety of different characteristics that make them hard to classify. Adaptive games targeting emotions have the capability to accommodate learners on the most individual level.

Adaptive challenge is a prime aspect of effective instruction and has been focused in the development of adaptive (serious) games for good reason. Not only does appropriate difficulty enhance learning, it is also responsible for the entertainment factor of a game. Emotion-driven adaptivity in this case can increase the granularity of adaptive challenge in serious games to make it even more effective. Adaptive game mechanics can help to find the right mix of design elements that suit each student and foster personal engagement. The benefit of emotion-driven adaptivity is thereby that the establishment of universal player types (whose existence is doubtful in any case) is unnecessary. Instead, just-in-time adaptation can be performed to fit the player's current requirements and interests. In the case of adaptive presentation, emotion-driven adaptivity can adjust to learning preferences and even factor in the current disposition of the learner. While someone might in general be a text-based learner, they might not feel like it after a day filled with reading and prefer instructions to be delivered via audio or image-based channels. The same holds true for an adaptive degree of interactivity. Direct adaptation is even capable of implicitly addressing the issue of what presentation or distribution of interactivity fits what kind of game. Game developers might fail to identify the best delivery style—if there even is one such combination—yet adaptive presentation will help find the mix of medium and interactivity that best resonates with the learner. Adaptive narrative strengthens a sense of autonomy in learners which in turn benefits motivation according to self-determination theory. As narrative relies strongly on the elicitation of emotions it can profit vastly from adaptive mechanisms directly targeting emotions.

However, with all these opportunities for developing emotion-adaptive serious games, several questions remain for future research to address. While a vast pool of potential design elements and methods for adaptation exists, it is, for example, still unclear what design elements should be adapted for what emotion in what kind of learner. Also, the technologies to implement adaptivity differ in their requirements and complexity in a way that not every technology is suitable for every serious game project or development team.

On the other hand, there might also not always be the need to develop emotion-adaptive serious games from scratch. There exist a variety of successful commercial games that can be leveraged to function as serious games. One way to accomplish this is by making use of commercial off-the-shelf (COTS) games in their original state and creating educational scaffolding around them (Breuer and Bente 2010). *Civilization* can, for example, provide historical settings (Shaffer et al. 2005), while *Scribblenauts* can be used to teach English vocabulary (Campos et al. 2013). This combines the advantages of entertaining games with established teaching methods. Other games like those of the *Neverwinter Nights* franchise come with editing tools that allow for the creation of educational mods (Soflano 2011). This requires a certain kind of expert knowledge but can lead to educational games that are able to leverage commercial game technology. However, while using COTS games provide an opportunity to create serious games or game-based learning settings without having to develop games from scratch, these solutions are not easy to use for the common educator. Novak and Nackerud (2011) as well as Van Eck (2009) present frameworks to help educators choose appropriate COTS game technology for their teaching purposes.

With regard to emotion-driven adaptivity, COTS games can serve a double purpose. On the one hand, adaptive technologies are already implemented in several commercial games as presented above. Where customization is possible, these could be used to study the effects of emotion-driven adaptivity. With regard to serving as serious games themselves, the same benefits from emotion-driven adaptivity as detailed in this section apply. COTS games could however have the advantage that a lot of content is already available for the adaptive processes to choose from.

## 1.6 Conclusion

This chapter shed light on the importance of an emotion-sensitive adaptive game approach that fosters task persistence and improves in-game behavior, learning processes, and performance by recognizing and responding to emotional states which might be harmful and/or fruitful to learning. As emotions are in some way part of the interaction between the player and the game, we posit a micro-adaptive approach that is a fine-grained player-centered automatic dynamic approach for adapting game characteristics such as their mechanics and representations on players' emotions as a target. As this approach demands a representation of the player's current emotional experience during gameplay, game research was reviewed that focuses on the nontrivial task of recognizing players' emotional reactions during gameplay. A variety of methods to measure emotions was presented, each with advantages or disadvantages. However, this field of research is still nascent leading to important avenues for future work, including the combination of several methods. Besides the question how to detect emotional states during gameplay, the purpose of this chapter was to clarify how to leverage the results of measurement. Existing attempts toward the adaptation of game elements and implementation methods were presented. The problem with some existing examples of adaptively designed serious games still is that these generally offer only low granularity in their degree of adaptivity. Summarizing, the results of this review emphasize that more research on unobtrusive emotion recognition is necessary and a lot more thought needs to go into the design of steering adaptation taking into account dynamic player models.

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# Chapter 2
# The *Emotion Detectives* Game: Supporting the Social-emotional Competence of Young Children

**Merja Koivula, Kerttu Huttunen, Marleena Mustola, Sari Lipponen, and Marja-Leena Laakso**

**Abstract** The potential of digital games to enhance learning in different areas of child development has drawn increasing interest amid growing concern about children's emotional well-being, social-emotional difficulties, and problem behaviors alongside diminishing economic resources for intervention and habilitation. However, digital games designed to promote social-emotional competence are surprisingly scarce. In this chapter, we explore children's use of the digital game *Emotion Detectives* (*ED*), designed to promote children's acquisition of emotional knowledge skills (e.g., recognizing, appreciating, and understanding emotions and their expressions), prosocial behaviors (e.g., helping, sharing, comforting, and showing concern for others), and problem-solving abilities. Analyzing children's gameplay sessions in two Finnish day care centers improved understanding of children's gameplay experiences, social-emotional knowledge, and collaborative learning. From the double effect of practicing social-emotional skills simultaneously in the game and in peer interactions, *ED* has the potential to be an effective learning environment for children. The game's humorous features, creative opportunities, and possibilities to make progress while playing clearly motivated children to learn.

**Keywords** Social-emotional competence • Digital games • Learning • Interaction • Game-based intervention

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## 2.1 Introduction

Two main trends have motivated the application of digital game-based learning devices to enhance social-emotional learning in young children. First is the belief and, to some extent, the evidence that game-based learning solutions motivate and improve the effectiveness of learning (Robertson and Howells 2008). Second, even as concern about children's emotional well-being, social-emotional difficulties, and problem behaviors has increased, diminishing economic resources are available for affordable intervention services in many societies. Digital learning environments offer an easily accessible, widely usable, and cost-effective means to deliver services and aid in the learning of various contents and skills. However, not all digital games lend themselves to curricula, and ensuring whether a particular digital game can enhance learning is critical. Some games, for instance, have little educational value not simply because they are games but because they lack pedagogical design and game-based learning principles. Many researchers are not interested in examining whether the content of a digital game is relevant to educational purposes but, instead, assess whether the structural characteristics of the game could benefit the educational and social processes surrounding the educational experience (Hong et al. 2009).

In this chapter, we critically reflect on both the content and the structural characteristics of *Emotion Detectives* (*ED*) (Emotion Detectives 2016; Huttunen et al. 2015), a new digital game based on research findings concerning the key factors in social and emotional development (see e.g., Denham 2006) and funded by the Finnish National Board of Education. In a theoretical sense, *ED* can be considered a research- or evidence-based intervention tool. However, empirical evidence is needed to evaluate its impact on children's social, emotional, and behavioral development. This research focuses on 5–6-year-old children's gameplay interactions while playing *ED* in pairs. The research goal was to gain understanding of children's gameplay experiences, social-emotional knowledge building, and collaborative learning through exploring their interactions, decision-making, and expression of opinions during gameplay.

The use of game-based learning in early childhood is increasing rapidly (Peirce 2013; Stephen and Plowman 2014), but the scientific discussion on the use of digital technologies in early childhood education appears polarized: digital technologies are considered either a problem and threat to children (Blum and Parette 2015; Nolan and McBride 2013; Stephen and Plowman 2014) or a possibility and resource (McClure and Sweeny 2015; Mustola et al. 2016). In order to overcome the unnecessary polarization of these phenomena, research-based evidence on the potential of digital games to enhance learning in different areas of child's development is needed.

With the advances in computer technologies over the past 30 years, a flood of new ways to communicate, provide, and deliver psychological treatments has emerged. Among psychobehavioral treatments, various Web-based interventions have grown in importance because they have proven to be both feasible and powerful at delivering various forms of behavioral interventions (Spence et al. 2016). With young children, these interventions typically occur through the employment of digital games. There exists a great need for such interventions independent of geographical location, family social-economic status, or children's special needs for support. Moreover, Web-based interventions offer one solution to a lack of sufficient local clinical services and frequently long waiting lists (Spence et al. 2016).

## 2.2 Importance of Digital Games as Intervention Tools

Typically, interventions in social-emotional development have been comprehensive, large-scale, curriculum-based programs implemented in day care centers or school settings. Various Web-based interventions for children have also been developed (Spence et al. 2016). Most are games which appear to be highly attractive to children (Holloway et al. 2013). Digital games for young children are being developed at an exceptionally fast rate. According to Marsh (2010), more than 150 virtual worlds targeted at children and young people were available in 2010, and new products for the youngest children were being released every week (see also Holloway et al. 2013). However, there are few developmentally appropriate games for the youngest children and, furthermore, a general lack of research in this area (Peirce 2013; Sung et al. 2008). In particular, studies on the impact and effectiveness of games are rare, and only a fraction of the research on games is targeted at early childhood learning (Peirce 2013). This is a serious deficiency because research shows that new media, in addition to providing entertainment, influences young players' attitudes, social behaviors, and information processing in many ways (Wartella et al. 2010).

Digital games can be considered effective tools for early intervention for a number of reasons:

1. They are effective vehicles for learning because they offer tireless opponents and enable endless repetition, drilling, and feedback (Bradshaw 2010).
2. Children are intrinsically motivated to navigate the playful or fantasy contexts of digital games (Koivula and Mustola 2015).
3. They offer a cost-effective tool because children can engage in the exercise or habilitation at any place and time, without expensive and often difficult-to-access clinical treatment (Peirce 2013).
4. Games serve as a dynamic assessment tool for evaluation and diagnostic purposes because they provide information on children's skills development and difficulties and a means for remedying or improving skills (Ifenthaler et al. 2012; Shute and Ke 2012). However, few digital games focus on social-emotional learning despite their inherent potential to evoke emotions, influence social behaviors, and generate a high level of positive emotional engagement (Conati 2002; Habgood and Ainsworth 2014).

Contemporary approaches to game-based learning consider an appropriate match among game design, learning content, and players' developmental stage to be highly important (Peirce 2013). Designing and creating the pedagogy of games for young children demand careful consideration of children's needs for imagination, creativity, play, participation, and social interaction, among others (Habgood and Ainsworth 2014; Mustola and Thompson 2016; Peirce 2013). To understand the possibilities and affordances of digital games as fruitful, supportive learning environments, it is important to evaluate not only the effectiveness of the game through the outcomes in children's skill development but, even more so, the processes through which these outcomes are achieved. We also need to explore the spaces for learning, interaction, and participation which games provide for children. Early childhood pedagogies have generally shifted away from highly structured approaches to more child-centered approaches which encourage children's participation and agency. Therefore, it is important to explore how a learning game which is based on research-based knowledge of emotion recognition and on clinical experience in the habilitation of children's communication and which targets increasing children's social-emotional competence can motivate children and provide possibilities for their agency.

## 2.3 Promoting the Development of Children's Social-emotional Competence Through the *Emotion Detectives* Game

Social-emotional difficulties are among the most severe and growing concerns in young children's development (Prinz and Sanders 2007). Preschool-aged children already exhibit social-emotional difficulties, with the prevalence estimated from 10–15% to 25–30% (Carter et al. 2004; Prinz and Sanders 2007). Certain constitutionally based problems (e.g., low inhibition), behavioral issues (e.g., impulsivity, overactivity), and difficulties in language development (Van Agt et al. 2011) are considered critical neurobiological factors which increase children's risk for various social-emotional difficulties. Children's social-emotional competence has been found to affect not only their peer relations (Denham et al. 2002; Fabes et al. 2001) but also their academic success and later employment (Denham et al. 2002). Theoretical and empirical research has shown that children with positive social and emotional skills demonstrate resilience when confronted with stressful situations (Greenberg et al. 2003; Masten and Motti-Stefanidi 2009). Research has also pointed to a positive correlation between measures of children's social and emotional skills, including emotion regulation and measures of later psychological health (Greenberg et al. 2001). Therefore, it is important to support children's social and emotional skills as early as possible before difficulties emerge and become prevalent and cumulative.

Previous research has suggested that children's social and emotional skills are partly linked to emotions and partly to socially responsible behavior. However, these two areas are deeply interconnected and usually are present simultaneously (Denham et al. 2002). Children have the innate ability to feel emotions, but the cognitive processes needed for emotion regulation only begin to develop after the first year of life. Moreover, the ability to combine emotional and cognitive information and, for instance, use different strategies to analyze one's own emotional experiences and emotionally arousing social situations emerges only around age 6 (Izard et al. 2002). This process of development suggests that children need adults' support and guidance in dealing with emotions and in learning emotion recognition and regulation strategies (about the development of emotions, see, e.g., Widen and Russell 2010c). The development of emotional skills requires that children become aware of their emotions and those of others (Harris 2010). Naming, discussing, and gaining an overall understanding of what emotions feel like are central to learning to recognize emotions.

*ED* is a game-based intervention tool for supporting the abovementioned behaviors and skills. This freeware is grounded in and follows the social-cognitive approach to social development and adjustment, particularly Crick and Dodge's (1994) model of social information-processing mechanisms. The core theoretical assumption underlying *ED* is the strong interrelationship among emotions, thoughts, and behavior. By increasing players' emotional knowledge and understanding and influencing their thinking, the game can promote their emotional and self-regulation skills and constructive behavior. Curriculum-based social-emotional programs, such as Second Step, also use this approach.

Unlike the few existing intervention tools focused on only one dimension of social-emotional competences (Bölte et al. 2002; Golan et al. 2010; Tanaka et al. 2010; Tseng and Yi-Luen 2011), *ED* is designed to support and enhance young children's acquisition of emotional knowledge skills (e.g., recognizing, appreciating, and understanding emotions and their expressions), prosocial behaviors (e.g., helping, sharing, comforting, and showing concern for others), and problem-solving abilities (e.g., social problem-solving behaviors, negotiating social conflicts) (Denham 2006; Eisenberg 2000). Like digital games in general, *ED* offers good opportunities for experiencing and rehearsing intense emotions due to its powerful audiovisual effects, emotional nature, and invitation to identify with the featured characters (see Ceranoglu 2010).

It is of the utmost importance that games, especially those of an educational nature, meet the needs of children with very different skill levels. *ED* is designed for ages 5–12 and allows players to select the desired difficulty level. The player (or an adult) can set the difficulty of the office tasks (explained in detail later) by selecting a fixed level of easy, moderate, or difficult. The adaptive game setting uses a stepwise progress as the player proceeds from levels requiring basic skills to more challenging ones. In this setting, players start at the moderate level and are given easier or more difficult tasks based on their success in playing. The aim of the adaptive game setting is to keep players' motivation as high as possible.

*Story Line and Structure of the Game* In the game, the player sets up an Emotion Detective office and attempts to solve various social and social-emotional problems with the character Aksu, a virtual assistant. Players compete against similar enterprises in town and have to increase the reputation of their newly founded office. Players collect fame points by devising solutions and practicing their skills in the tasks presented. When the Emotion Detective and Aksu have earned enough points, they receive new tools (e.g., Emotion Radar, Magnifying Glass, and Emotion Glove), with which they can proceed to the next level in the game. Exercises in *ED* are divided into two main modules: office and field tasks.

*Office Tasks* *ED* consists of many kinds of emotion-related tasks which fall into four main categories: (1) identification of faces and recognition and naming of facial expressions, (2) recognition and naming of tones of voice, (3) matching of tones with facial expressions, and (4) categorization and matching of emotion words or identification of synonyms and the valence of emotion words. The game comprises 23 office task types in which each has three difficulty levels. The hierarchical model of face processing developed by Tanaka et al. (2003) provides the basic structure of the facial expression tasks. Developmental data from the research literature were used to select the emotions in the game, especially for the different difficulty levels and the various alternatives for the multiple-choice tasks (Castelli 2005; Golarai et al. 2006; Harris 2010; Hopyan-Misakyan et al. 2009; Leppänen and Hietanen 2001; Sauter et al. 2013; Widen and Russell 2010c).

The game tasks demand holistic face processing and part-based facial recognition, along with recognition of facial identity and expressions. In several tasks, players match facial expressions of either one person (e.g., in memory games) or across different people (see Fig. 2.1). Faces of altogether 12 persons appear in the material expressing up to eight different emotions each, and the game randomizes the faces for maximal variability and learning.

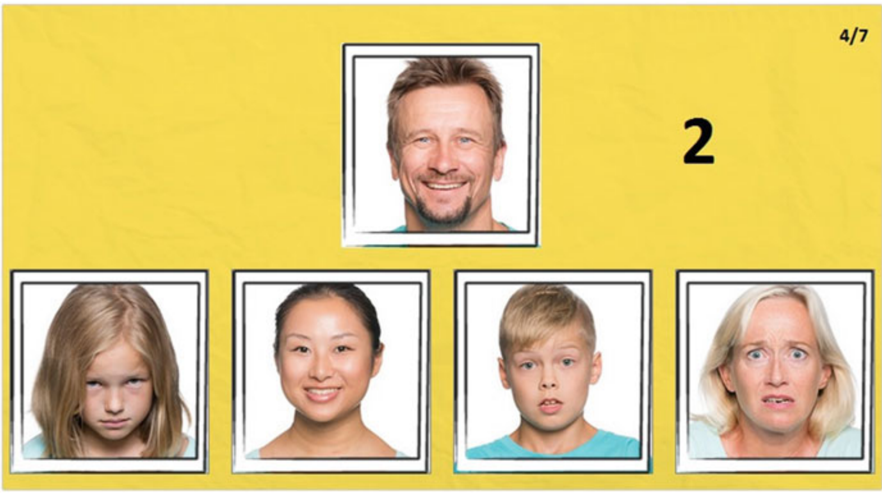


**Fig. 2.1** Office task in *ED* requiring the player to match two identical facial expressions

A more difficult level of facial processing is involved when the player is asked to identify emotions based on an image of a face showing only the eyes and eyebrows (Wolf et al. 2008; Sadr et al. 2003). In addition to identification of faces and expressions, visual and auditory memory skills are practiced in the *ED* game. For example, visual short-term memory plays a central role when players need to store the order of three successive images of facial expressions in memory. In addition to the ten face-processing tasks, *ED* has three tasks on the recognition of tone of voice. Whereas other office tasks focus on one modality, some office tasks require combining visual and auditory information to reflect on everyday communication situations. The game also supports the development of children's emotional knowledge. In seven tasks ordered by difficulty level, players produce emotion labels, in other words, name emotions (Widen and Russell 2010b). Players thereby enlarge their emotion vocabulary through these tasks which require, for instance, identifying and learning new synonyms of emotion words.

*Field Tasks* In field tasks, players receive an alert and leave the office to solve social or social-emotional problems for various characters. Thirteen field tasks are presented through social stories shown in cartoons with speech bubbles. The recorded lines are spoken by children and adults, the latter who are mostly professional actors. All field tasks have the same basic structure. Players first *recognize emotions* using the Emotion Radar, then *identify the reason for the emotions* using the Magnifying Glass, and, finally, *select the best solution to the conflict* and resolve it in both thoughts and concrete action using the Emotion Glove. All the solutions require thinking about other characters' viewpoints, knowledge, and feelings and negotiating conflict resolution accordingly. The topics of the social stories follow developmental trajectory, and the facial expressions and tones of voice used in the tasks must be interpreted and understood in social settings. The tasks also give practical tips, such as how to control strong affective states. One such tool is Robin et al.'s (1976) *turtle technique*, in which one takes a few deep breaths to reduce tension.

The themes of the field tasks cover a wide range of social situations including both conflicts and prosocial behavior: approaching others; belonging to a group; fair play; lying and betrayal; helping others; peer competition; aggression (direct, relational, and indirect); self-regulation; self-efficiency; discrimination (due to clothing, skills, and physical appearance); feelings of being lonely, isolated, or different; shame; fears; and shyness. The social stories in the field tasks provide training in many fundamental social skills: initiating interactions, approaching others, politely making requests, expressing positive or negative emotions, taking turns, thanking others, asking for help, and expressing empathy (Fig. 2.2).

The game is designed to engage children through active, reciprocal interaction with the character Aksu, the Emotion Detective's virtual assistant. Players receive feedback on their selections in multiple-choice tasks from Aksu and the Emotion Radar (the robot) (Fig. 2.3). Aksu, in particular, simulates normal language-acquisition processes in which adults use positive emotion talk and mental state language. The feedback includes simulation of natural techniques used by skilled

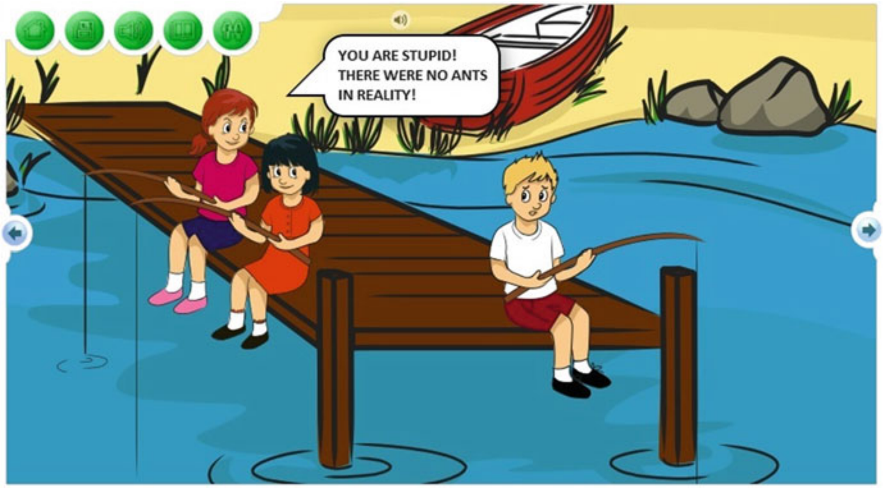


**Fig. 2.2** *ED* field task in which a boy is mocked for misunderstanding a metaphor (The dialogue is translated from Finnish)

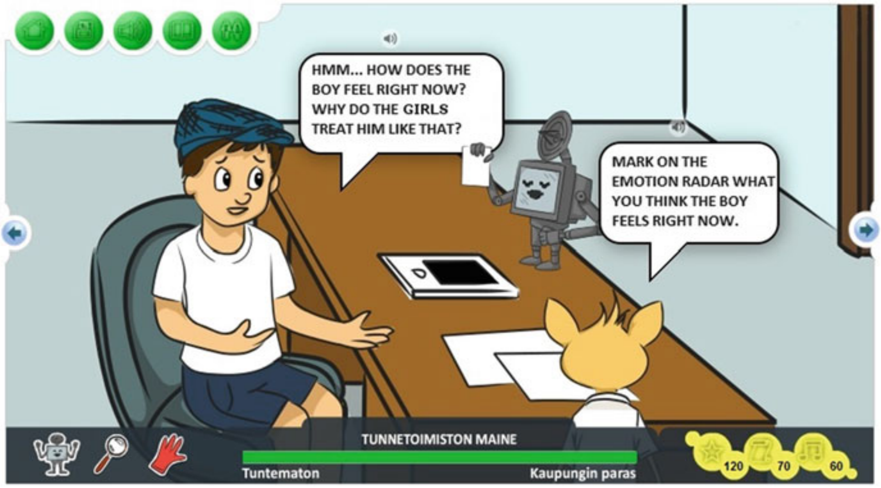


**Fig. 2.3** Virtual characters Aksu and the Emotion Radar urge the Emotion Detective to identify emotions in the *ED* game

parents (Brownell et al. 2013): (1) use of emotion labels; (2) elicitation of emotion labels from the child ("How does x feel?"); (3) explanations of emotions ("He was unhappy because ..."); (4) descriptions of desires ("What does x want to do?"); (5) internal talk ("What does x think about?"); (6) other mental state talk (vocabulary, metaphors, and idioms); and (7) provision of empathy inductions. The aim is to support players' self-reflection, increase their ability to recognize different forms

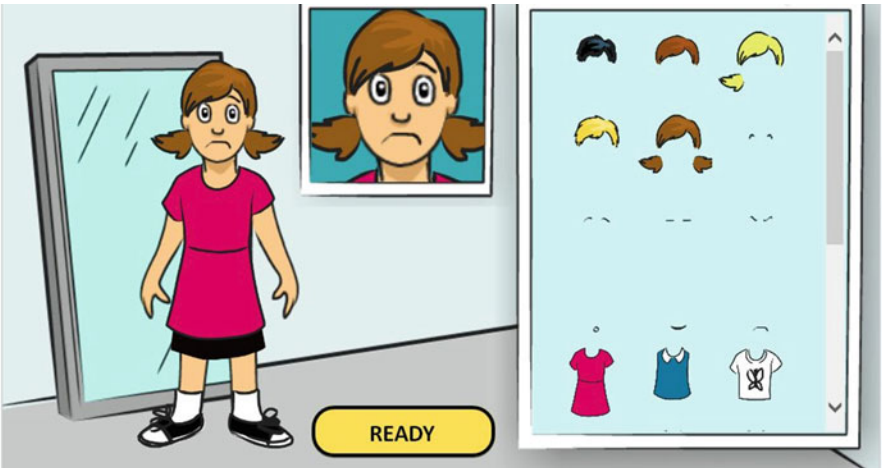


**Fig. 2.4** Mannequin of Mr. Eagle Owl the Dressmaker with a sad face

of rejection, and thereby prevent later aggression in children who do not find easy acceptance in peer groups. Children's social information-processing patterns have been found to partially mediate the effects of peer group rejection on later aggression (Dodge et al. 2003). Accepting other children in peer groups provides all children with opportunities for social growth and the development of social skills.

*Support of Players' Creativity* The game design aims to allow room for children's creativity to increase the attractiveness of the game. According to the player statistics embedded in the game, one of the most popular mini-games has been The Mannequins of Mr. Eagle Owl the Dressmaker (in Finnish, *Herra Huuhkajan mallinuket*). In this mini-game, the player can design the faces of mannequins by selecting eyes, eyebrows, and mouths which express different emotions and can dress the mannequins by selecting their hair, clothes, and shoes. After completing a mannequin, the child is asked to select the emotion on its face (Fig. 2.4). Additionally, the player can choose to save and print the dressed dummy. Children can also create their own cartoons in StoryTube (*Tarinatuubi*), a cartoon construction program which is an extension to *ED*. StoryTube can be launched by clicking a link embedded in *ED*. For the cartoons, which can be saved and printed, players can select various scenes, characters, and objects featured in the game and add speech bubbles to create narratives.

The usability of the game has been increased by providing mini-games. The 23 office tasks can be selected individually on the webpage (http://emo.oph.oodles.fi/minipelit.html) if the player does not have the time or interest to play the entire *ED* game with all the field tasks and progressive accumulation of points. This mini-game option is especially helpful for parents, teachers, and therapists who want to select the needed office tasks and to plan how long playing them will take.

## 2.4 Adults' and Peers' Role in Supporting the Child's Play

Human–machine interaction (HMI) is not necessarily adequate for digital games to support children's social-emotional development at an optimal level. According to previous research (Erhel and Jamet 2013), feedback from others is important for good learning results. The child, therefore, needs another person, whether an adult or another child, to create a human–human–machine triad which enriches the contents of the intervention through the interaction of the child–adult or child–child pair. When *exploiting scaffolding* or, as Vygotsky (1978, p. 90) called it, *the zone of proximal development*, a child who cannot accomplish a task alone can succeed and learn with the help and encouragement of a knowledgeable adult or a more competent peer.

In *ED*, adults are urged to support children in playing because adult–child interactions and communication support learning. Parents' encouragement of their children's active participation in discussing others' emotions has been found to be beneficial in children's emotional development (Brownell et al. 2013). *ED* exploits the features of parent–child interaction effective in supporting children's recognition of emotions and social-emotional development. Adults who support children in playing the game are urged to give feedback on the children's playing, to use emotion words in conversations with the players, and to expand the themes introduced in the game by discussing emotions related to children's experiences in everyday life. The game provides instruction materials for adults on how to support children in playing, topics to discuss, and how to promote children's self-reflection ability.

*ED* is also designed to promote peer learning. The gameplay setup allows two (or more) children to play while seated side by side and sharing the screen. This seating arrangement precludes direct engagement but places participants in an intimate position. The averted gazes might allow children to more easily chat or start conversations about their gameplay and the themes in the game. The multiple options and solutions in the game offer players possibilities for joint discussions and reasoning. Players receive direct feedback on their responses. Aksu, the virtual assistant, comments on players' actions and uses gestures, vivid tones of voice, and abundant emotion state talk and mental vocabulary. Such feedback, when used in parental talk, has been shown to support children's language skills and social-emotional development and to be associated with fewer behavior problems (Brownell et al. 2013; Curenton and Craig 2011).

## 2.5 Empirical Observations on Children's Gameplay Interactions

This section presents observations of children's learning dispositions and possibilities for shared thinking (Mercer and Littleton 2007; Wegerif et al. 2003) and (emotional) engagement (Schoenau-Fog 2011) during the *ED* gameplay. The aim was to identify what game-playing processes and qualities sustain engagement and learning in the target domain of social-emotional competence. To understand the possibilities, affordances, and limitations of digital games as learning environments, it is important to evaluate not only a game's effectiveness in achieving children's experienced motivation or skills development but more so the processes through which sustained motivation and positive learning outcomes are attained.

The empirical evidence was gathered from observations of the *ED* gameplay of 5- and 6-year-old children (six pairs in the first phase of data collection). A large dataset was collected on the effectiveness of *ED*, including the experiences of children and kindergarten teachers, and their evaluations of the game design using both quantitative (e.g., measuring children's pre- and post-intervention social-emotional competence) and qualitative methods (e.g., observations, interviews). The *ED* game intervention was conducted over 8 weeks. Each child played *ED* alone for a minimum of 1 and a maximum of 2 h per week and with another child 15–30 min per week in their day care center. Three game-playing sessions with each pair of children were videotaped during the first, fourth, and eighth weeks of data collection. The purpose of this periodic data collection was to detect any changes in children's gameplay. The aim was to analyze children's gameplay interactions and the context provided by *ED* game design. To do so, qualitative analyses, including content analysis and thematic analysis, were performed.

The first step in the analysis was to transcribe all the video recordings. The next task was to develop initial thematic categories and to examine them in detail by coding all the material. The unit of analysis was a meaningful phrase or sentence uttered during an interaction (taking into account the affordances of the game context). The following sections discuss preliminary findings from the children's playing of *ED* concerning: (1) the process of recognizing and naming emotions, (2) player interactions, and (3) players' interactions with the *ED* game. The aim of these analyses is to understand whether and how playing *ED* supports children's emotional knowledge, social-emotional competence, and collaborative learning.

## 2.6 The Process of Recognizing and Naming Emotions

To develop an understanding of emotions, a child must be able to identify different emotions (Widen and Russell 2010a). A child develops the ability to recognize specific emotions from facial expressions during the first half year of life, and this innate or prepared system forms the basis for later development of emotional scripts (Widen and Russell 2010a, 2010b). In building these scripts, the child learns by, for example, labeling emotion expressions and processing information about the causes and consequences of specific emotions (Widen and Russell 2010a). As mentioned, various tasks in *ED* target recognizing and naming different emotions.

Example 2.1 illustrates children's discussions about recognizing emotions. In this task, the player first must identify seven faces from a background scene, and each time a face is identified, the player selects from three alternatives which emotion is expressed on the face. In the examples given here, children are identified with codes: a capital C indicates a child, and a number identifies a specific child.

**Example 2.1**
*C2: Hey, this is nice!* [smiling] *Seven faces. This is nice.*
*C1:* [nods to the pair and looks at the camera for a while]
*(.)*
*C2: Hey. (.) So let's see that picture (.)*
*C1: Fun. This is good.*
*C2: Hmm.*
*C1: Shall we do this with* [a child's name]*?*
*C2: Yeah, I'll be the first one, and then it's your turn.*
*C1: Okay.*
*C2: Okay?*
*C1: Yes.*
*C2: I'll click here.*
*C1: Yeeess.*
*C2: And then angry (.) I knew it!*
*Adult: How did you know that it's angry?*
*C2: Well, because it looked that way.*
*Adult: But how did you know that it said "angry" there?*
*C2: Yes, I can read these.*
*C1: Then* [clicks the mouse]
*C2: Eeeh. You have to take the sad one.*
*C1: Sad is (.) above or below . . . which one?* [asks her partner in a soft voice]
*C2: Below.*
*C1: Okay, I thought that . . . (.) so, where do I click...there?*
*C2: There.*
*C1:* [Clicks the mouse]
*C2: Yay hehe* [smiling, rubbing hands together]

This example illustrates how the two girls played *ED*. They also practiced how to use a computer and mouse because as tablet users, they were not familiar with using a laptop computer. The girls were both interested in playing *ED*. They decided to choose a nice task and found a face recognition task to be rewarding. They felt joy when they correctly labeled the emotion, which they signaled by clapping their hands and praising one another. This example also shows their collaboration in playing the game. C2 was somewhat more competent than C1, who continuously asked for her partner's advice and confirmation as their game continued. C1 seemed to need scaffolding as she functioned in her zone of proximal development. Thus, for this pair, the gameplay promoted learning of emotional knowledge and the social skills needed in collaborative learning.

During the gameplay, the children exhibited some differences. Participants had different skill levels in the *ED* game; some also played it at home, so they were more competent at it than those who played it only in the day care center. In some pairs, the children negotiated taking turns in the gameplay, whereas in other pairs, there were conflicts. In Example 2.2, a boy (C3) and a girl (C4) practice recognizing facial expressions. This kind of discrepancy in skill level between learners can frequently result in peer tutoring and collaborative learning.

**Example 2.2**

*C3: Where is the sad one?*

*C4: Wait … it is...* [she pushes her partner's hand away from the mouse] *wait* [pushes her partner's hand away from the mouse]. *It is angry. The one below … below … yes …. Then where do you put the next one?*

*C3: Happy.*

*C4: That one* [pointing].

*C3: This is the bad guy.*

*C4: Angry, that is the one below... Wrong, the one below* [shows it on the screen] *… Then where do you put the next one?*

*C3: This one … the sun.*

*C4: It's not going there … it's that one.*

*C3: Angry.*

*C4: Happy. It's the one on the top.*

...

*C4: Is he … happy, sad or angry?*

*C3:* [Laughs when he gets the correct answer] *I know them myself … you don't have to* [help]

...

*C4: Wrong … Like that … then … is she … happy, sad, or angry? Wrong … Yes, you did those … Hey, you have to listen!*

*C4: You have to listen to those!* [her partner just clicks the mouse forward without listening] *… Click … Click!* [speaks more emphatically]

*C3: Okay* [talks to the game] *Stupid* [says to the game] *… Don't you get it.* [repeats what he hears from the game, laughs]

*C4: Hey … listen to those!* [as her partner keeps on clicking forward without listening]

*C3: I'll listen to this, at least.*

*C4: Click there, click there!* [pointing]

...

*C3:* [It is C4's turn to play, followed by C3] *Now I can do it.* [pulling the computer away from C4)

*C4: Wait, no, I can do it!* [pulling the computer back]

*C3: I will do, too!* [pulling the computer]

*C4: No!*

*C3: This is a joint game!*

*C4: You actually did have more time for play.* [pulling the computer]

*C3: Joint game!* [tries to pull the computer toward himself]

*C4: Wait … You did have more time for play than I had.*

*C3: Yes I can ... this is a joint game*. [The children continue arguing, and finally, C4 gives up to C3, and he takes over the game.]

In this example, C4 (a girl) clearly had more knowledge about the *ED* game and tried to help C3 (a boy) in gameplay. However, her efforts did not succeed: C3 was determined to play the game by himself and appeared to have his own style of gameplay. He did not listen to C4's advice but kept on guessing the answers and clicking on alternatives without thinking about which was the right answer. This frustrated C4 and finally resulted in a conflict between the children, who argued over whose turn it was to play. When it was C4's turn to play, C3 finally seemed to understand the goal of the game and tried to pull the computer away from C4, using the argument "This is a joint game" to justify his actions. In the end, C3 got his way, and C4 gave up the fight and lost her rightful game time.

In this situation, the children had different motivations for gameplay. C3 wanted to play by himself, even though C4 consistently tried to negotiate, give advice, and construct joint gameplay. If C3 had a more responsive mindset, this situation could have resulted in collaborative learning instead of conflict. However, for both children, this social interchange required practicing social-emotional skills and competence. Previous research (Koivula 2010) has suggested that this reluctance, as in the case of C3, to receive help and construct a joint, collaborative learning situation occurs more frequently in preschool-aged boys than girls. One explanation for this trend is that boys eagerly desire to emphasize their own gameplay skills and knowledge and so interpret receiving help as incompetence. This example illustrates the significance of player interaction for the construction of joint gameplay and collaboration.

## 2.7 Player Interaction During Gameplay

A number of studies have found that children's knowledge of their own and others' emotions forms the basis for their actions in specific social contexts. As Harris (2010, p. 329) states, "Children's ability to understand and predict their own emotions likely affects their decision making about what course of action to take." In addition, research has found that emotional communication cannot be separated from its social context (Saarni 2010). The social context of playing *ED* in pairs resulted in a variety of player interactions, ranging from minimal verbal communication between children to active collaboration and co-construction of knowledge. Here, the examples illustrate the findings concerning two categories of player interactions: (1) rules and negotiations about the gameplay and (2) children's ways of interacting and co-constructing knowledge.

### *2.7.1 Rules and Negotiations*

Most child pairs strictly followed the rules during gameplay. As the children started the game, they negotiated taking turns but had to continue doing so during gameplay, as Example 2.3 shows. Turn-taking was the main cause of conflicts between children.

**Example 2.3**

*C7: Shall I click here* [a certain picture]*?*

*C8: Don't. Take that one. Again, wrong one. And now one more, and then it is my turn.*

*C8: Hey!* [C7 takes control of the mouse.]

*C7: You have had more game time with this!*

*C8: Huh, no I haven't! I put . . . .! C7* [child's name]*! Do you know . . . is it okay that everyone plays the game twice, is it okay?*

*C7: Yes.*

In this example, a conflict about game time occurred between the children. These minor conflicts occurred quite frequently in the data. The first strategy children normally used was to take away the other child's finger from the mouse, but in some cases, the child also tried to take control of the entire laptop and move it away from the peer, as in Example 2.2. Only after these physical reactions did the children start verbal negotiations. However, some girls also developed innovative solutions for turn-taking in their gameplay. For example, a pair of girls agreed that one would move the mouse and the cursor while the other did the clicking, and the children collaborated in this way throughout the game.

From the perspective of *ED* game design, it is interesting to explore children's negotiations of the events of the game and their interactions to recognize emotions or resolve social situations in the game. The aim of the *ED* game setup is to support and promote these kinds of interactions. Example 2.4 illustrates a situation in which two girls attempt to find the correct solution together.

**Example 2.4**

*C6: Okay, I think it is this one* [the correct one] *. . . Could it be this?* [selects the wrong one] *Oh, man! That was . . .*

*C5: I pointed to the other one.*

*C6: Is it this one? . . . . Yes, it is this one, isn't it? Are you thinking about this as well?*

*C5: I tried to point it and then you just picked the other one.*

*C6: Well, you know what . . . I . . . well, I . . .*

*C5: I just show like this.*

*C6: That's the one . . . you know what?*

*C5: Wait!*

*C6: Well, I just did not see . . . I just thought that you pointed to that one.* [The girls look at each other.]

*C5: What on earth?* [The girls try to understand what is happening in the game.]

*C6: Okay ... click . . .*

This example shows a typical gameplay situation as both children actively participated even though it was C6's turn to select the correct answer. C5 pointed to the option on the screen she thought was correct. Although the children followed the rules regarding turn-taking, the member of the pair observing still participated by giving advice and pointing to the correct answers.

Interestingly, there was also some competition between the children. They all wanted to succeed and were glad when they selected the correct answer, but in some occasions, the competition resulted in one child underrating another's performance, saying, for example, "You did not get it right." or "You can't play correctly." When the children encountered challenging tasks, they turned to each other for help, but some problems also emerged in these situations. An unmotivated member of a pair might not give assistance despite the other child's request.

Children's motivation (see Deci and Ryan 1995) to play the game was a key element in successful peer collaboration, but the most significant contributing factor was the social relationship between the children. Our data showed that, in gameplay, pairs of friends were more likely to succeed in collaboration and learning together, whereas non-friends were more likely to encounter challenges and problems. Koivula (2010) reported similar results: peer collaboration (collaborative learning) among young children was most successful between friends. Friends were more willing to negotiate with each other and quickly resolve conflicts and had motivation to construct shared activities.

### *2.7.2 Children's Ways of Interacting and Co-constructing Knowledge*

As Examples 2.2 and 2.3 show, some conflicts occurred between children during gameplay. However, the conflicts were typically short and did not result in the breakdown of the shared gameplay activity. Children's collaborative interactions mostly proceeded without significant problems. The child pairs displayed a range of productive interactions during gameplay. Of particular interest were children's flexible transitions between solo gameplay and collaborative endeavors. On one hand, it was important for children to succeed by themselves, expressed in such statements as "I knew that!" "I know what are the right ones." "I am good at this." and "I have done this before. It is that one." On the other hand, the children were motivated to create the context of shared gameplay and emphasized the collective nature of the gameplay situation. The collaborative interactions during the gameplay were represented in such statements as "Shall we do this one?" "Let's take the tablet games again!" "We guessed that!" or "We got the Magnifying Glass! Exciting!" This we-talk indicated the commitment of both members of a pair to joint gameplay and created the feeling of togetherness in the gameplay activity, which lay foundation for collaborative learning (Koivula 2010; Koivula and Hännikäinen 2016). Example 2.5 shows a child seeking assistance from and co-constructing knowledge with a peer but refusing help from an adult.

**Example 2.5**

*C5: Now, let's take the second one, shall we?* [The children listen to the second alternative.]

*C6: No, not even close.* [They listen to more options.] ... *No* ... *oops.* [They look at each other.]

*Adult: What happened now?... I don't know ....*

*C5: Let's listen* [to options and instructions].

*C6:* [sighs and makes sounds with her tongue].

*C5: Surprised.*

*Adult: Do you need some help?*

*C5: Nooo ...* [does not want help from the adult]

*C6: Eeeh ... I don't know right now ... Okay, exhilarated comes next.*

*C5: I know what that one is ....*

*C6: Mmph* [to the game] *Tell...which one of these?*

*C5: Wait, let's see ... embarrassed ... no ... Insecure ... no ... ashamed*

*C6: Let's take ... let's see if it is insecure* [the correct answer].

*C5: But we just took it, just a while ago!*

*C6: No, we took embarrassed.*

*C5: Was this supposed to be ...* [listens to the option from the game].

*C6: That was not exhilaration ... no, that was not embarrassed. This one is embarrassed, but in there it is ... let's try this one ... for real that one. This is so hard! This is so hard*! [Finally, they find the correct answer.] *Right!* [C6 smiles and looks at the camera for a while.]

In this example, the girls, C5 and C6, both struggled to find the correct answer. The kindergarten teacher was nearby and offered to help, but they did not want the teacher's assistance. They relied on each other and wanted to succeed by themselves. Their interactions illustrate the construction of joint knowledge through discussion. Together, they recognized and named emotions and tried to find the correct alternatives. C6 became somewhat frustrated when this turned out to be a challenge. Such interactions were quite typical in the data. Children sought help from each other, and especially when difficulties emerged, they relied on their peers.

Surprisingly, the presence of the kindergarten teacher lessened the amount of interactions between children. Sometimes, children sought help or confirmation from the teacher and often called for the teacher to come and see their improvement, but the more long-term presence of the teacher decreased mutual interactions among children. On one occasion, the researcher observed that a pair involved in gameplay did not talk to each other despite the researcher's guidance. In other observations of *ED* gameplay, these same children had lively conversations with each other. An explanation for this difference might be that the pairs were committed to playing the *ED* game together and relied on each other but did not want to fail or reason together under the eye of the teacher (or researcher), who was an adult authority.

In the present data, thus, it seems that, for the children playing the *ED* game in the setting of a day care center, interactions materialized in either peer interaction or adult–child interactions, and these two did not mingle seamlessly.

The design of the *ED* game, as stated, supports adult–child and peer interactions. Children's co-construction of knowledge occurred when they needed assistance or support from their partner, as in Example 2.5, but also when they were committed to making choices and proceeding in the game together. One particular task which resulted in productive interaction was the office task The Mannequins of Mr. Eagle Owl the Dressmaker.

**Example 2.6**
[The children have made two mannequins for Mr. Eagle Owl.]
*C7: Eh, which one of these? Teacher?*
*C2: Teacher!!!* [shouts for the teacher]
*C7: We don't know what this one is.*
*C2: Surprised, it is surprised.*
[The teacher reads the alternatives aloud.]
*C7: We don't know.*
*Teacher: Well, you can choose yourselves what* [emotional expression] *you want for the figure you have made.*
*C7: This one.*
*Teacher: It says emotional.*
*C2: Yeah, emotional.*
*Teacher: Do you both think it is emotional?*
*Both children: Yes.*
*Teacher: Well, then you can choose that one. And then click ready.*
*C7: Uuuu, now that mannequin. Take that kind of fancy.*
*C2: I'll make a boy ... a father.*
*C7: This is our dad!* [Both start laughing out loud]*...No, choose hair like that.*
*C2:* [laughs]
*C7: No, choose black hair* [both are laughing again]. *This is better.*
*C2: No, this is better.*
*C7: Like that. Then take the sad face.*
*C2: No, the angry one. It is angry. This will soon look angry.* [Both are laughing out loud.]
*C7: Then let's dress him with some silly clown clothes!*
*C2: No, we have forgotten to put this ... this will be on his head.*
*C7: We cannot put a skirt like that!!*
*C2:* [laughing]
*C7: Put this one.*
*C2: No, these ones. Which? You can decide.*
*C7: This* one [Both are laughing again]. *Still, shoes like that ...*

Example 2.6 illustrates joint collaboration in making mannequins for Mr. Eagle Owl. Both children contributed to the choices made and discussed the various options. In this case, the children started to add humor and have fun designing the third mannequin. They decided to make the mannequin a dad, and C7 thought that it illustrated her father. They chose the color of the hair and wanted to put funny clothes on the mannequin. C7, however, did not want the mannequin to have a skirt. The children laughed a lot about the silly mannequin. Such shared fun between children occurred on many occasions throughout the data and served the important functions of motivating the children's gameplay and strengthening their relationships. The children frequently joked together and commented on the events or feedback given by *ED*.

## 2.8 Children's Interaction with the *Emotion Detectives* Game

HMI is a new research field even though humans have long operated machines. The concept of HMI is usually broken down into four categories addressing the use of computerized machines: safety, performance, comfort, and aesthetics. These categories are often associated with four human factors: physical, cognitive, social, and emotional (Boy 2012). When analyzing the interactions between humans and machines, the essential factors are the quality of the interaction and the machine's ability to create a satisfying experience of agency for the human (Murray 2011). In analyzing the structural characteristics of game design, it is important to consider how the game design supports or enhances the processes and elements considered meaningful for promoting effective learning. These include putting players into simulated real-life situations and enabling shared experiences (collaboration) during gameplay.

As described, two dimensions of social interaction were included in the *ED* game design. First, *ED* introduces children to social situations in which they need to recognize emotions and select appropriate solutions to conflicts. Second, the game setup offers possibilities for joint learning. Prensky (2001) has identified six key structural elements of games: (1) rules; (2) goals and objectives; (3) outcomes and feedback; (4) conflict, competition, challenge, and opposition; (5) interaction; and (6) representation. The examples from the data touch upon game rules and objectives and also conflicts and challenges. Next, the qualities of the interaction and feedback in *ED* are described, focusing on both the game itself and the motivational aspects of the game.

In their interaction with *ED*, children sometimes expressed a lack of motivation to play *ED* and the desire to do something else: "This is a stupid game!" "I don't want to play anymore." This is boring!" In some cases, it was best to stop playing the game and continue doing so at another time when the child felt more motivated to play. However, these statements of reluctance were quite rare. Children mostly had an enthusiastic outlook toward playing *ED*. In the data, utterances, such as "Hey, this is nice!" "Yeah!" "I know this one!" and "This is easy!", were more common than negative feedback. Children felt that it was important to move to the next level of the game and make the correct choices. When they succeeded and got rewards, they felt enthusiastic, smiled, clapped their hands, and shared the joy of success with their partners. One girl had invented a sort of short rhyme which she shared with her partner when they got the right answer. The girls scratched each other's hands and chanted: "Kittens obey what their mommas say!" They repeated this action every time they had success in the game. Example 2.7 illustrates the importance of rewards.

**Example 2.7**

*C6 and C7 have played the ED game for some time but have not received the Magnifying Glass and have started to wonder if there is something wrong. They receive a package in the game and call the kindergarten teacher to come and see that they have finally gotten the Magnifying Glass. The teacher compliments them, and both children are extremely happy and scream for joy. They look at each other, and then they look at the amount of reputation points they have received in the game.*

In Example 2.7, the children wanted to receive the Magnifying Glass, which would enable them to proceed to a new task. They felt that they should already have earned the item and wondered if something was wrong with the game. When they finally attained the goal and received the Magnifying Glass, their joy was evident, and they wanted to share their joy with the teacher. The game design motivated children to learn to recognize emotions and practice social-emotional skills, represented in their desire to earn high scores and to know the right answers and in their annoyance when they chose the incorrect alternative.

When the children did not succeed in the emotion recognition tasks or in resolving socially complex situations, *ED* offered feedback. The feedback usually gave encouragement to try again and think harder but could also include humor, as Example 2.8 shows.

**Example 2.8**

[Children say the feedback from the *ED* out loud.]

*C2 and C7:* [along with Aksu, the virtual assistant in the game] *"But that did not succeed very well. What do you think? Shall we close our office and move to Timbuktu? Maybe there we can have a job as a wall decoration."*

*C2 and C7:* [along with the voice of the Emotion Detective] *"Don't overreact now. Let's take a little break and play again after a while."*

This repetition of feedback and other statements in the game was common among players. The children anticipated what feedback they would receive and reinforced it by saying it themselves. When the feedback was positive ("We are the best ones!"), children also repeated it. In addition, the game included some humor. For example, saying the phrase "red-butt baboon" made the children laugh and want to hear that comment again. Children also joked about the words they heard in the game and imitated the sounds they heard, such as the metallic, robot-like sound of the Emotion Radar. These exchanges illustrate the interactive nature of children's gameplay in *ED*. They gave feedback to the game, repeated the feedback that the game gave to them, and, with their partner (and with the game), improved their gameplay.

## 2.9 Discussion

The empirical data collected revealed the diverse gameplay situations the children experienced while playing *ED* in pairs. Based on the empirical extracts presented, it is clear that the children learned social-emotional skills through playing *ED* and through social interactions with their partner. As stated, social-emotional competencies, broadly understood, consist of various skills, such as recognizing and naming emotions and the ability to behave in a socially responsible way. Through the double effect of practicing these skills in the game while engaging in peer interactions, *ED* has the potential to be an effective learning environment for children.

The gameplay situations presented did not always appear to be ideal, purely positive learning scenes. They also involved conflicts, arguments, submission, and assaults. The game itself did not generate such incidents, but conflicts arose from peer interactions, reflecting the nature of real-life social situations which inevitably are both easy and challenging. Such social difficulties offer an important opportunity for children to practice and enhance their social and emotional skills. The presence of an adult, however, is important to intervene to help children solve their arguments in cases of major conflicts.

The empirical data enabled understanding what qualities of *ED* motivated the children. The game's humorous features (e.g., the possibility to dress a man in a dress) and funny feedback (e.g., Aksu suggesting that the player should give up and move to Timbuktu) fascinated the children. The opportunities to acquire various tools and to progress in the game were also essential. Similarly, the children seemed to enjoy the opportunity to be creative, as in the office task to dress a mannequin in different outfits and select different emotional expressions for its face. The research information gained from observing actual gameplay situations with children provided crucial knowledge about what features of digital environments motivated the children to learn.

In the future, research could be more specifically targeted at the processes and qualities of educational games and gameplay that promote engagement, collaborative learning, and positive learning outcomes. More in-depth theoretical and empirical knowledge of these processes and quality issues regarding digital games could improve understanding of the effectiveness of game-based learning in various areas of children's early development.

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# Part II
# Games for Music Education

# Chapter 3
# Designing Music Games and Mobile Apps for Early Music Learning

**Szu-Ming Chung and Chun-Tsai Wu**

**Abstract** For the purpose of developing music game apps for early music learning, the authors establish a research of game design, testing, and validation. Before explaining each stage of this research, the past and current music games for learning and entertainment are investigated. This chapter also explores theories and teaching approaches that need to addressed if mobile applications are to be developed, created, and evaluated. The *agile software development method* is implemented to assist a successful development of game design on Android system with a multi-touch screen. In order to find problems and possible solutions of designing e-learning games, in the course of testing, the authors collect data based on empirical observations and gameplay records on the tablets. For often unattainable assessment in music education, a combination of the *System Usability Scale* (SUS) and *Questionnaire for User Interactions Satisfaction* (QUIS) is recommended to validate a music game system and mobile applications.

**Keywords** Music games • Apps • Android system • Multi-touch screen • Early music learning

## 3.1 Introduction

Six years ago, Yen came to me (Szu-Ming) for consulting his master program. He was inspired by my music teaching and intended to make it an interactive installation with three elements—a drum set, pentatonic keyboard, and guitar chord player. Together we created an interactive installation with a 2D flash game on computers. This creation was patented by the government office.[1] Afterward we investigated the players/users' satisfaction with this game system and interactive

[1]Chung, Szu-Ming and Chen, Chih-Yen (2012). Interactive Installation of Music Instrument Set (M441181) by the Intellectual Property Office MOEA, ROC.

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installation. It turned out to be the first e-learning game on music in all my recent years' research (Chung and Chen 2011). The purpose of all these research became clearer gradually in 6 years. First my research creates a certain strategy of teaching and learning music. Second, my research is based on learning problems and solutions in teaching music. Third, technology is a new media for helping students' learning, creating music, and making new sounds. Mobile applications are the easiest tools for us to create music learning games. Certainly mobile devices have their limitations in sensing and sounding system. Perhaps testing young children is the most difficult process. We continue our research in creating music mobile applications for e-learning games. Before creating any e-learning games, the purpose of music creations is my primary concern, either in music learning or in gameplay. If the purpose of music learning is to create music, the purpose of creating e-learning games becomes apparent to me, which should provide learners with opportunities of experiencing music, sensing music, attaining knowledge and skills in music, and eventually creating music. In the planning stage, the related studies include cognitive development, musical development, teaching method and materials, and game content and interface design.

In 2015 the population of Internet users under 12 years old exceeded 1.41 million in Taiwan. The survey Happiness in Digital Families conducted by Microsoft in Taiwan reported that 61.1% of 1068 families used e-learning games for interaction and 52.3% of children favored mobile device to learn from or entertain themselves. The demand for e-learning applications is increasing rapidly. Among these applications, there are few for musical learning. Therefore, we propose research in the following related topics:

1. For past and present digital musical games for entertaining: (1) to explore the game designs with musical elements, (2) to discuss their limitations in musical learning, and (3) to suggest possible music learning with the aid of e-learning games.
2. For musical sequence and creativity in game design: (1) to design rhythmic, melodic, and chords sequential learning in musical games, (2) to improve them with applications of music teaching approach and theoretical concepts.
3. For mobile applications: (1) to develop a musical game on Android system and multi-touch screens, (2) to present technical issues and problems, and (3) to propose solutions to problems.
4. For e-learning experiments and evaluation: (1) to discuss qualitative and quantitative research in musical evaluation, (2) to evaluate usability of applications with the *System Usability Scale* (SUS) and to validate it with the adaptive ratings, and (3) to validate the interactions with the *Questionnaire for User Interactions Satisfaction* (QUIS).
5. Finally, the author will summarize some design principles of an optimal game system and mobile applications for music learning and evaluation.

### 3.1.1 *Digital Music Games for Learning and Entertainment*

Digital video games require the player to have the abilities of fast reaction time, good memorizing capacity, and good sustained time to do things (attention or selective attention). These abilities are referred to our cognitive system and its components of receiving visual, auditory, and tactile information (Loftus and Loftus 1983). Just about the same abilities are referred to in game-based learning. If we examine the digital musical games for entertaining purposes on the market, we find the musical elements usually are combined with abilities (such as shooting) that not so critical in a learning game.

In this section, we will discuss and analyze the past and present digital musical games: to explore the game designs with musical elements, to discuss their limitations in musical learning, and to suggest possible music learning with the aid of e-learning games.

#### 3.1.1.1 For Learning

1. Drill and practice: This kind of e-learning games provides music students with a disciplined and repetitious exercise to perfect knowledge and skills in music, such as music theory, music reading, solfège (sight singing), and so on. *Music Tutor Sight Read* is a quiz game designed for learning to read (and write) music. *Read Music Notes HN* focuses on a grand staff (treble and bass clef) reading drills.
2. Step sequencer for sequencing and mix: *Rhythmic Trainer* is a simplified version of a MIDI sequencer of rhythmic patterns for creating and performing. *G-Stomper Rhythm*, *G-Stomper Studio*, and *FL Studio Mobile* are very similar to MIDI sound editors for sequencing and mix, which depend on a MIDI sampler, controller, and synthesizer.
3. Virtual instruments lessons: These kinds of apps are mainly designed as learning tools for guitarists, drummers, or keyboard players, such *as Chord! Guitar Chord Finder*, *My Piano Assistant*, and *Drum Kit*. How music theory drill and practice help these learners is the main concern of their interface design.

#### 3.1.1.2 For Entertainment

1. Some rhythm-based games, such as *Dance Dance Revolution* (feet coordination), *Donkey Konga* (hand coordination), and *Guitar Hero* (finger coordination), are equipped with a sensing board of feet, hands, or fingers for interacting with the screen interfaces. The visual design on interface with many distractive animations and colorful icons enhances the difficulty of gameplay. However, many of their rhythmic patterns don't match up with the song rhythms. They could even ruin our sense of rhythm if we focus more on visual cues and reactions

to them on a scrolling screen, either on sideways or straight railways. Particularly the "right-on-the-target" hitting sounds could be very annoying while playing with background music/songs.

2. In 1987 Japanese Toshio Iwai developed a music-shooter game: *Otocky*. It was the first combination of generative music and shooter game. The spaceship has firing balls shooting eight directions each with a different note. These notes can be quantized with the background beats. The player improvises notes along with playing a shooting game. The player can change instrumental sounds and weapons. After collecting enough musical notes, the game would unlock a music editor for the player to improvise freely. The musical elements are produced as a melodic line with percussive beats and sparkled with sound effects. *Rez* is an advanced form of generative music shooter game. Though *Rez* is a simple rail shooter game, the player's actions with musical or sound effects are locked to the certain tempi, rhythmic and pitch patterns of the background music. The complexity and density of music progress through constant layered musical and nonmusical sounds. Compared to *Rez* with limited resources, *Free the beat* is half-shooter and half-music interaction game, giving some freedom to create rhythmic patterns.
3. *SimTunes* is a melody-based game. The player creates music by choosing colored pixels with assigned music notes. The primary feature of created artworks is to play the arranged composition with visual effects. The music structure presents a multiple lines of percussive and melodic sounds. It is a much sophisticated interactive artwork associated with musical composition.
4. Creative instrument *TENORI-ON* is designed by media artist Toshio Iwai and Yamaha. It is a digital musical instrument for creating music. The player has to learn how to create music on this light and electronic sounding system. It is an interactive platform for playing and creating music at the same time. As many music editors (software), it requires much learning to create music and less game-playing elements. Compared to virtual instruments, *TENORI-ON* can be viewed as a concrete musical toy, which is fun to explore, manipulate, and play on for many open-ending music creations.

In a nutshell, the above games intend to create or interact with music soundtracks while playing the games. Creating or interacting with music is also the central ideas of all these entertainment games. For entertainment, with a special gaming interface as in category 1 or using an ordinary PC or console, the manual interactions on game interface provide certain kinesthetic feelings of playing instruments. A game without music or sound effects background could diminish the pleasure of playing. The complexity and density of constant layered musical and nonmusical sounds often cause uneasiness and tiresomeness. Involving musical elements in gameplay opens a new venue for developing video games. Rhythm-based games are referred to the abilities of our cognitive system, especially the visual, auditory, and tactile coordination. In such gameplays, accuracy perhaps is more important than rhythmic sensing and feelings. Apparently cognitive abilities are more wanted in music educational games. Besides considering only music contents in a traditional way of music learning as apps mentioned in the section of "A. For learning . . . ," the authors intend to embody traditional music learning in game-based learning based on children's cognitive development, music development, music learning approaches, and their ideas in practice and children's play.

### *3.1.2 Cognitive Development*

Piaget's developmental stages occur in a consistent order (Gruber and Vonèche 1977)—sensorimotor, preoperational, concrete operations, and formal operation usually in a sequential order. Furthermore, the developmental changes occur in almost all children according to a fairly standard timetable (Swanwick 1988). The purpose of exploring Piaget's theory is to design an age-appropriate game with consideration of musical intelligence and physical capacities in young children. During the early childhood years, children rapidly develop their symbolic function or semiotic function in cognitive concepts, representational thought, time, space, and movement and speed (Gruber and Vonèche 1977). *Assimilation* and *accommodation* describe how the organism utilizes something from the environment and incorporates it. At the same time, the organism responds to stimulus and actively changes it internally. These "functional invariants" occur continuously in cognitive development in a balancing manner. When assimilation is more than accommodation, the child is playing. When accommodation is more than assimilation, the child is imitating. When they are in balance, the most adaptive condition (e*quilibration*) is displayed. Cognitive development also consists of a succession of changes whose structural units are called *schemata*. Cognition develops continuously; however, the results are discontinuous and termed as sequential periods, subperiods, or stages by Piaget (Phillips 1969). Cognitive development helps us to understand what students can do or how they develop their cognitive abilities. For example, 4-year-old preschoolers fall under the stage of preoperational subperiod of concrete operations. The preoperational child:

1. Can differentiate signifiers of words, images, etc.
2. Can classify images according to their content or structure (visual, auditory, etc.)
3. Is egocentric in their representational thought and cannot take another person's point of view
4. Tends to focus on the successive states of a display
5. Lacks the reasoning ability of cause and effect and a hierarchy of categories

These characteristics can be influenced by several factors, such as maturation, physical experience, logicomathematical experience, social experience, and equilibration (Sigel et al. 1981). Cognitive stages imply what game content and music materials we can apply and integrate with the music video games/applications for different age groups.

### *3.1.3 Musical Development and Perception*

Almost all human beings have (96%) innate musical ability unless they have genetic defects (Lehmann et al. 2007). A child's development is affected by many factors, such as basic biological potential, maturity, experience, opportunities, interests, education, family, peers and sociocultural connotations (Welch, 1998). However, musical development is influenced by experience, opportunities, and motivation (Sloboda's definition of influencing factors; Mihill 1993). Other researchers emphasize acculturation (enculturation) and the impact of cultural experiences. Many research prove that musical development is closely related to the environment at home. The music or songs they hear at home are greatly different from that in schools.

Inspired by Piaget's developmental psychology, many music studies found that there are stages in the musical development of children. Although the distinction is not clear, it can be drawn out as a spiral diagram of musical development (Lehmann et al. 2007). From birth to 4 years old is the first stage. At this stage, children will explore a variety of sounds including musical sounds, instrumental sounds, and singing voices. Their explorations will focus on volume, dynamics, and tone quality, and they will try to repeat the rhythmic and melodic patterns. Five to nine years old is the second stage. At this age, children will try to convey emotion through music and stories, especially through songs, and will also notice changes in the speed and intensity of sound. They can follow traditional music activities and demonstrate a sense of rhythm, tempo, and fixed music phrases.

Young children in their first 3 years of life can perform more consistent beats in their babble and sing when they can perform smoother movements (Elliott 2004). Some children younger than 3 years can sense the beat of music (McLauglin 1998; Suzuki 1969). More than half of 3-year-olds can tap to a steady beat, based on a test with computerized rhythmic performance in the United States, South Africa, and Australia (Flohr et al. 1998). In the research of synchronization of beats, preparation, and attention, "tapping" is the most accurate practice of playing or keeping steady beats (Bregman 1990). Humans tend to hit 20–60 milliseconds earlier than the constant beats of the duple meter due to the sense of balance (Wohlschläger and Koch 2000). Accents appear to help in accurately executing steady beat tapping (Semjen et al. 1992).

Another study shows that mere listening to piano music can activate auditory information and the motor cortex (responsible for body movement, including preparation, sensory guidance, and control of movement) (Bangert et al. 1999). This indicates that sound mapping is in parallel with motor activities in the musical brain. Based on Elliott's analysis and the figure of types of representations, the genuine representation (physical experience) and symbolic representation (communicative experience) interact between the corporal movements and musical sounds, verbal words, and visual signs. In early childhood, physical activities and practical experience usually enhance and stimulate genuine mental representation. Such development is also found true in music learning. Genuine musical representation can only be achieved by musical doing.

Humans possess auditory as well as visual perception abilities to easily differentiate melodic patterns (gestalt theory). Melody is constructed by successive pitches with shapes and directions. Humans can also perceive melodic figures (musical themes) and background (instrumentation/orchestration), which are not necessarily true to different octaves. On the contrary, within an octave, the gestalt principles function well on proximity, similarity, good continuation, and coherence (Dowling 1994). Without any musical training, 6-year-old children are no different from 11-year-olds in perceiving musical sound including the main melodies accompanied by the harmonic progressions (Colwell 2006).

### 3.1.4 Knowledge Formation and Musical Knowledge

The formation of knowledge requires perceptual experience to make sense of daily activities (Polanyi and Prosch 1975). Based on Croce (Swanwick 1994), the hierarchy of knowledge is formed through the sensory impressions and intuitive knowledge to reach logical knowledge. Croce assumes that logical knowledge continues to accumulate through intuitive knowledge linked by dynamic forms, images, and multiple representations. Thus, the intuitive knowledge is the core transformation between perceptions/sensory impressions and significant meanings/-logical knowledge in the human brain.

The above analysis of how humans acquire knowledge is similar to Bruner's knowledge mapping [12]. Bruner believes that sensation, intuition, and analytic knowledge represent the knowledge system of human reality: the *enactive* (sensation), the *iconic* (image thinking), and the symbolic (abstract thinking, reflecting, and communicating).

### 3.1.5 Children's Play and Learning Motivation

A sense of competence and self-efficacy is related to a child's value of an activity (Parncutt and McPherson 2002). According to Flow theory, the equal activity levels of challenge and self-perceived competence will most likely engage children in efficient learning (Csikszentmihalyi 1990). Children's play may not ensure successful learning in school, but it can offer possibilities of learning (Singer et al. 2006). Children in play are observed to be relaxed and in pleasure. Vygotsky (1967) claimed that play creates the zone of proximal development of the child: the law of the development of higher mental functions and the notions of instruction preceding and shaping development (Bodronva and Leong 2015). Though Vygotsky's definition of play does not include physical actives, games, object manipulations, and explorations, however, the authors view them as play and believe that children's play implies learning with or without guidance and also is applied in musical game-based learning.

## 3.2 Musical Applications on Android System

Through applying the above theories, game-based learning provides experience and prepares children to assess their knowledge and abilities in music. Such musical applications should consist of an optimal selection of age range-appropriate content and interactivity integrated with musical activities. The next three sections discuss the design of selected musical contents and their multi-touch interactions on the Android system.

### *3.2.1 Music Teaching Approach and Content*

Orff's (1895–1982) concept of teaching music starts with early childhood education and rhythmic training. All development stages center on musical rhythm, beginning with the initial language, including poetry, fairy tales, drama, rhymes, proverbs, poetic prose, calls, folk songs, pentatonic, church modes, accompaniment, rhythmic instruments, improvised language performances, folk dance, dance, mime, and other percussion-related activities (Warner 1991). One central element of Orff-Schulwerk approach is to use pentatonic scale, which seems always to sound good in improvisation (Goodkin 2002). Any vibrating sound creates overtones, and its first eight overtones are pentatonic scale—A, C, D, E, and G (Fig. 3.1 Pentatonic scale on C). Pentatonic scale is commonly known as melodic construction of Taiwan-Xiao-Diao (Taiwanese Minor Tune). In Western music, pentatonic construction is also found in many cultures, such as Irish folk songs, Hungarian folk tunes, Native Americans, and so on. The two gaps between pentatonic scale (mi to so and la to do), together with other elements (rhythm, timbre, etc.), create big diverse music among these cultures. It is the minor feeling of Taiwan-Xiao-Diao distinguished from others. Though selecting pentatonic scales to compose music in this game is for cultural implication, the melodic construction is not limited to minor scales (pentatonic scales start and end with re, mi, and la), giving more freedom of improvisation.

There are two consonant triad chords (Figs. 3.1 and 3.2); consonant triads (C and A triads) for pentatonic melody can be played in without fa and ti. Two-part writing is to learn about basic and partial triad construction, the third and fourth above or below melodic line (Fig. 3.1) and partials of inverted triads (Fig. 3.1 Inversion of triad). The diminish B chord is excluded because its root cannot be included in an improvisation game.

Kodály approach uses so-fa syllables and hand signs combined with rhythmic syllables to work as the start of musical learning activities for young children. Hand sign syllables combined with body movements are especially suitable for children who cannot read. They are also good preparation for music reading.

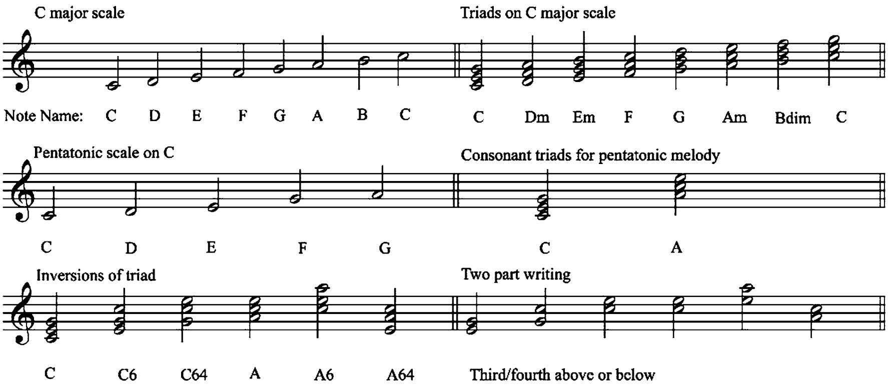


**Fig. 3.1** Melody and triad chords can be used in improvisation game

**Fig. 3.2** Icons for apps

Orff and Kodály approach share great resemblance (Wheeler and Raebeck 1972). Both of them advocated the sequence of music learning and process of language learning (patterns, rhymes, and proverbs), singing (two-tone to five-tone pentatonic melodies), playing musical instruments and accompaniment (Orff used percussion instruments and Kodály used recorders), improvisation, and rhythmic activities (various sounds made by the body, corresponding to a variety of accompaniment, songs, games, and musical forms).

## 3.2.2 *Multi-touch Application and Music Learning*

A multi-touch application developed with Adobe Flash on the Android system motivates human-computer interaction by single/dual/multi-touch tapping, pinching, swiping, wobbling, and shaking. It not only substitutes for keyboard and mouse but also offers direct manipulation in interaction with a computer interface. Through detecting the deficiency of multi-touch technology on the Android system (swiping and pinching) and preoperational children's incompatible sensorimotor skills (eye-hand coordination and hand-finger gestures), we integrated the age range-appropriate musical contents with compatible sensorimotor skills for multi-touch interactions.

### 3.2.3 Music Game Content and Sequential Learning

Bruner's knowledge map (Bruner 1971) constructs its symbolic system through sensory experience and imagery thinking. Based on Bruner's knowledge map, we can design an intuitive way (perceptual experience) for players to interact with the game content. Such a game design offers an auditory-visual experience of rhythms, melodies, and chords. Through interacting with the game interface, the player establishes his/her knowledge map of the Western music system. This game's design refers to the perception and cognitive learning process mentioned in this chapter. It applies Orff and Kodály's philosophies and employs their approach to inspire music intelligence in children and prepare them for music learning later in life.

Designing a music game system and game interface for young children, the learning content progresses in a sequential two levels each with four stages arranged from easy to difficult in rhythmic, melodic, and intervallic patterns and pentatonic improvisation. Each stage begins with an animation of the gameplay. The following parts explain how the game content is to be developed in Level 1 and Level 2.

**Level 1**

1. Tapping game: this game establishes the feeling of steady beat and basic rhythmic patterns. By tapping, the player/learner has to match the beating sound (1 beat per a second) from an easy beginning of two beats, to a medium difficulty of four and eight beats, and then to a hard difficulty of 12 and 16 beats (two or four beat patterns).
2. Ladder game: this game establishes listening skills of absolute pitches on a seven-step ladder (the order of a rainbow colors represents the order of an octave scale of do, re, mi, fa, so, la, and ti).
3. Marble game: this game establishes the feeling of up/down melodic lines. The player has to use a shaking gesture to match the up/down melodic lines. If replaying the stage, the player will hear similar up/down melodic lines with different instruments.
4. Ocean bubble game: this game offers a space for player to compose music freely by using knowledge learned in prior games. The player can tap single-colored bubbles which float up randomly. After finishing a 16-beat melody, the player can listen, compose a new one, or end the game.

**Level 2**

1. Hopscotch game: this game provides listening experience of intervals (steps)—dissonant seconds (steps of two) and consonant thirds (steps of three). By matching the boxes of hopscotch, the player can hear and know consonant/dissonant intervals.
2. Block-stacking game: this game provides listening practice of consonant thirds and dissonant second (similar to tile-matching puzzle game).

3. Necklace game: this game constructs the knowledge of musical form. The player can choose four note patterns (by different colored tones) to create a necklace (musical forms of AA, ABA, AABA, ABABA; capital letters of A and B represent different patterns).
4. Ocean bubble game: this game appears again as in Level 1. Instead of flicking single-colored bubbles, the player can choose any string of four colored bubbles (four note patterns) emerging from the ocean space. After finishing four four-note melody—16 beat altogether—the player can listen, compose a new one, or end the game.

## 3.3 Technical Issues in Developing Applications on Mobile Devices

Educational games integrate cross-field knowledge and skills through communicating and conveying different ideas between cross-field scholars. All involved developers of multimedia, sound design, and technology have to attain a full understanding of educational objectives in game design. This section explores and discusses the technical issues and problem-solving in game development on an Android system with multi-touch screen by Flash ActionScript 3.0. To accomplish effectiveness and simplification, we adopted Agile Software Development method in the developmental process.

### *3.3.1 Agile Software Development Method*

Software development has to be flexible to respond to different demands and rapid changes nowadays. Traditional information development method emphasizes on the planning stage. The documentation has to be exchanged between customers and developers by written details (Nerur and Balijepally 2007). Such a developmental method lacks flexibility in rapid change of software progress (Nandhakumar and Avison 1999). Agile software development method emphasizes sense-and-respond relationship between customer and developers. It requires flexibility and leanness and also maintains simple and clear design (Conboy and Fitzgerald 2004), which also focuses on feedbacks and changes (Cockburn and Williams 2003). Through constant direct communication and collecting consecutive follow-ups, developers can respond users' needs agilely. This method emphasizes teamwork between game developers, designers, pedagogical designers, and learners to act cross functions. In developmental process, team members review, integrate, test, and feedback continuously, which can satisfy customer's demands and maintain the flexibility.

### 3.3.2 *Game-Based Applications for Music Learning*

In the development of music game-based applications, we confronted many problematic issues. Acting as the multiple roles of designers, developers, and customers, we have to take advantages and avoid disadvantages of creating a game system for music learning by utilizing ActionScript on an Android system. The following section presents the issues we have to deal with while developing Level 1. It definitely reflects the problems within the process.

#### 3.3.2.1 Visual Design

Games executed in mobile devices prefer to use the collective ideas to create a specific style. Two-dimensional cartoonish motifs and patterns are employed to attract young children's attention.

Concerning the illiterate young children, realistic instrument graphic designs of four instrumental families plus piano represent the logon accounts. In the process of choosing the graphic design, the young children can recognize and remember the image of instruments. For every game, the player has to choose one instrument to log on. The images are gray out to avoid repetitions. The gameplay data is also collected and saved on each account for later analysis (Fig. 3.3).

The goals of intuitive game are to experience the steady beats, pitch listening and matching, melodic direction, and improvisation. The replay of games is not limited to win or lose. The player can choose to replay if he/she intends to for the reason of learning or experiencing again. Therefore, the interactive buttons only consist two sets of graphic icons: one for the players and the other for the testers. Every

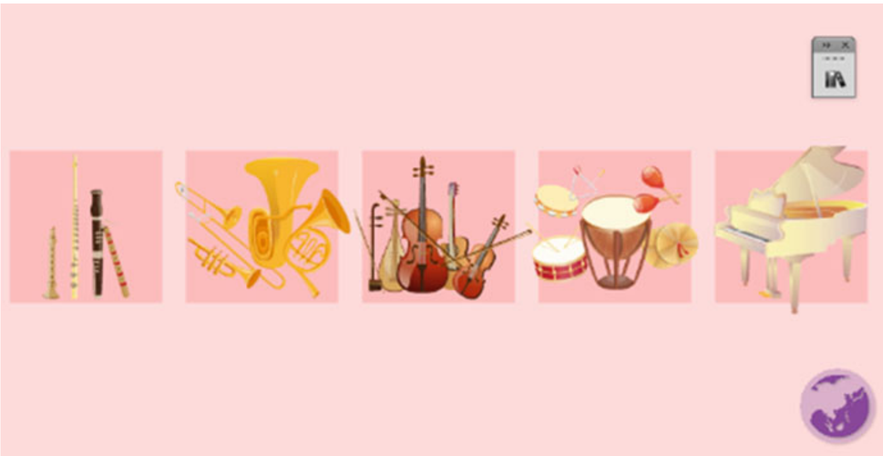

**Fig. 3.3** Musical instrument family menu

**Fig. 3.4** Gameplay demos

game shows "replay" (circle arrow icon) and "pass" (check mark icon) when the demonstration or the game is over. The testers can navigate to the collected game data by pressing "home" (house icon). For creating an emerging game environment or feedback, we intend to design short animated videos played in the gameplay. Short 2D animations also are created to demonstrate gameplay before the game starts (Fig. 3.4).

#### 3.3.2.2 Sound Design

The sound design should consider the tempo, volume, pitch level and range, tone quality of instruments, and appropriate music sound for the game content. The music sound file is closely related to the length of frames. The music has to precisely associate and synchronize with the images. The tempo of frames usually is decided by the flow of animation. But, the attacking point of music sound mandates in the animated images (frames). Vocal feedbacks are recorded by adults but its pitch is raised to children's voice. The sounding system on tablets cannot fully express the integrity of music, which is the most troublesome problem we have to deal with. The sounds are not always played on time and sometimes missed totally. The possible solution is to export sound files limited in length and size. Unless for performing a piece of music, the single notes are preferred in the integration of sounds and images. The condensed music files as MP3 are more workable with games on mobile devices for not to drag gameplay speed.

#### 3.3.2.3 Mapping Music Elements onto Gameplay

The programmer maintains constant communication with the curriculum designer. This process circulates a cycle of thinking, planning, programming, pretesting, formal testing, and collecting feedbacks from testers. And then a prototype of application is created, modified, and refined by suggestions from the curriculum designer. Once the prototype is finished, it puts in pretest. The prototype is refined many times by publishing many versions until the final release. This process emphasizes review, feedback, and modification for teaching objectives. The following section explains the technical issues of four games (2.3: Level 1):

### Tapping Game (Steady Beat)

The time differences in sensing change the integration of associated frames and sounds. Tapping game involves listening, seeing, touching, and coordination. The timing of music sounding reflects the visual animation and reaction from the game player. The feeling of music pulsation is usually attained from listening and performing. In this gameplay, considerations include timing of music sounding synchronized with the animated images and the reaction time. The attacking time of musical sound has to be set earlier than the visual images to reach the synchronization of associated sound and image.

### Ladder Game (Pitch Matching)

This game offers an opportunity of a fundamental problem-solving technique of "try and error." In the process of pitch matching, the player taps the right steps on a rainbow-colored ladder to match the intervals played by the game system. To avoid confusion, only the right matched sounds are played. The music files can only play as expected in compressed format on tablet, such as MP3 files.

Through pretest, overlapped music sounds often happen in gameplay because "try and error" always is used to solve problems by preschoolers. In programming, a stop command can avoid repeating the execution.

The pitch-matching accuracy is closely related to children's vocal range, and preschool children's vocal range is limited to the octave higher than middle C. Though some preschoolers can sense the musical pitches in different octave range, to avoid collecting confused data after gameplay, the pitch range of play samples and matched pitches is played within the same octave above middle C. In respect of music, materials should be selected within the children's capabilities, and the interval samples are created as unison, seconds, and thirds within a pentatonic scale above the middle C.

### Marble Game (Up/Down Melodic Lines)

The player can hear up/down melodic direction by shaking the tablet. Through right and left shaking, the ascending and descending stepwise melodies are played to comply. The data collecting only records the left-right directions, which cannot reflect any differences between players. The data collecting thus is changed to record the playing times.

The preschool children take the tablet as a toy and shake it in many directions. The shaking angles are limited to 30°. Beyond 30°, the program cannot respond correctly. Children have to learn to adjust the angle and solve this problem.

Ocean Bubble Game (Improvisation on Pentatonic Tones)

Instead panning, the gesture is set as single tap—tapping the colored bubbles to improvise a pentatonic song. Though the diatonic pitches and rest notes are the first to be included in this game, concerning children's listening capabilities and Taiwanese folk song characteristics, the five tones (do, re, mi, so, and la) of a pentatonic scale above the middle "C" are synchronized with rainbow-colored bubbles and emerging randomly for players to choose and tap. After finishing 16 notes (implied 44 m with four measures long), the improvised song plays at a tempo of 60 (per minute) and blinks the bubbles while playing the matched tones. The data collecting records each song and its tones.

## 3.4 Qualitative and Quantitative Research

Regarding user age, psychological cause, interface usability, and evaluating validity and credibility, we design a qualitative research validated by quantitative research. To reach such goals, we run a testing process to collect all the data by participant's observation, video recording, and gameplay results on mobile device database. The tested 21 subjects consist of nine children at age 4 and 12 at age 5 from a local private preschool in Taichung, Taiwan. They are tested in a normal classroom with no sound proofing. During the test, children are offered tablets running the apps and a headphone set to isolate them from outside noises. Over the course of 10 weeks, 15-min sessions (may be lasted shorter or repeated), once a week, were conducted for each child. Data is collected for certain evaluation dimensions, such as attitudes, interactions, and problem-solving, including subitems of active/passive, interested/noninterested, emotional expressions, physical/verbal responses to visual/auditory cues, and exploring possible gameplay/inquiring for answers to problems. Two researchers outside the development team analyze the data and draw out graphic maps for comparing their analysis results. Through such data analysis, we attain the validated results from a combination of qualitative and quantitative methodologies (Chung and Wu 2016). The findings are (1) the purposeful aims of game design and multi-touch applications influence children's attitude, interaction, and problem-solving; (2) the musical game designed as multi-touch application tends to motivate a preoperational child's active attitude and interactions with tablet computers; (3) the musical game that requires practice provides a challenge to preoperational children; (4) the musical game design with creative functions and recorded audio files encourages interactions and repetition and requires no prerequisite musical knowledge and skills. Children refer to sensory data and intuitive knowledge in such gameplay, which possesses the potential to expand to a higher level of symbolic knowledge.

### 3.4.1 Usability Measurement and Interactive Interface

The interface of a game system and interactive installation should define functions and operations as providing users with a clear and logical process for effective learning. The usability measurement emphasizes the user-centered design principles and fits the user's physical and psychological needs (Benbunan-Fich 2001). *Deutsches Institut für Normung* (DIN) suggested that usability of an interface design should focus on effectiveness, efficiency, and satisfaction (Seffah et al. 2006). Preece (2001) defines a product's usability as simple and operating with ease. Nielsen et al. (2002) recommend ten principles and five guidelines to design an interface with highly acceptable usability. Rogers et al. (2007) indicated that data of user's attitudes and their ways of interacting and operating with interface are a good way to measure usability.

*System Usability Scale* (SUS) is established to measure small sample sizes with ease and reliability. SUS scores above 68 are considered acceptable results. Higher scores are esteemed higher evaluation. Its content included ten questionnaire items with five responses from one to five points that range from strongly disagree to strongly agree (Table 3.1). Due to the constructing of positive and negative questions, for odd items subtract 1, and for even items subtract responses from 5. All the respondents were asked to record their immediate response for each item. The calculation used SUS scoring principles (Brook 1996, 1986). An adjective rating scale is added on to the SUS score. It is suggested by Bangor et al. (2009) to validate the SUS score and usability.

Questionnaire for User Interaction Satisfaction (QUIS) is a tool developed by Human-Computer Interface Lab (HCIL) at the University of Maryland at College Park. It investigates a user's subjective satisfaction with specific concepts on an interactive interface. Based on Likert scale, it measure users' overall

**Table 3.1** SUS of game system with an interactive installation

| The tasks you perform with this system | | | | |
|---|---|---|---|---|
| I would like to use this system | | | | |
| I found the system too complex | | | | |
| I thought this system was easy to use | | | | |
| I think that I would need the support of a technical person to be able to use this system | | | | |
| I found the various functions in this system were well integrated | | | | |
| I thought there was too much inconsistency in this system | | | | |
| I would imagine that most people would learn to use this system very quickly | | | | |
| I found this system very cumbersome to use | | | | |
| I felt very confident using this system | | | | |
| I needed to learn a lot of things before I could get going with this system | | | | |
| Response format | | | | |
| Strongly disagree | | | | Strongly agree |
| 1 | 2 | 3 | 4 | 5 |

reactions to nine specific interface factors: screen factors, terminology and system feedback, learning factors, system capabilities, technical manuals, online tutorials, multimedia, teleconferencing, and software installation (http://www.lap.umd.edu/quis/). Based on such investigation results, the researcher can revisit the designing principles of game system and modify the interactive interface.

## 3.5 Summary

For reasons of attainability, portability, and convenience, we propose a series of game-based e-learning applications. These applications are complete, put in test, and data collected. To summarize the entire research, we analyze and discuss the digital musical games for entertaining and limitations; cognitive and musical development; music educational theories, teaching approaches, and learning sequence; optimal developmental process of Agile Software Development method; some design principles of an optimal game system and mobile applications for music learning; qualitative and quantitative research in music; validity and credibility by the *System Usability Scale* (SUS) and *Questionnaire for User Interactions Satisfaction* (QUIS) for a music game system and mobile applications, including interactive installation. From the tested results published in *Serious Music Game Design and Testing* (Chung 2014) and *Mobile Device Applications for Head Start Experience in Music* (Chung and Wu 2016), we conclude that (1) age-appropriate game content inspires the players and engages them in gameplay; (2) the purposeful aims of game design and multi-touch applications influence children's attitude, interaction, and problem-solving; (3) the musical game design with creative functions and recorded audio files encourages interactions and repetition; (4) music mobile applications require no prerequisite musical knowledge and skills; and (5) children refer to sensory data and intuitive knowledge in such gameplay, which possesses the potential to expand to a higher level of symbolic knowledge.

To investigate the usability and interactivity, we applied SUS and published the results in *Acupressure Game System with Interactive Installations* (Xu et al. 2016). The researchers chose families with mid-childhood children (6–12 years old) as test subjects. Twenty-five parents and 25 children from 25 families, with a total of 50, participated in the pretest, and 31 parents and 32 children from 31 families, with a total of 63, participated in the formal test. Their tasks were to use the system with interactive installations without specific instructions and then rate the equipment with the *System Usability Scale* (SUS). Though this game design is not related to music mobile applications, we attain positive results of mobile applications and interactive installation which are created by Scratch for Arduino (S4A). As for the current and future research on music mobile applications and perceptual interactive design, we intend to investigate the usability and validate interactive interface and installation by the SUS and QUIS. Since the attainment and assessment have not been easily verified and the qualitative research in music education has been criticized by subjective observations and controversy arguments, an eclectic combination of qualitative and quantitative research might be the better answers to music educational research.

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# Chapter 4
# Shake and Create: Reappropriating Video Game Technologies for the Enactive Learning of Music

**Kenneth B. McAlpine**

**Abstract** This chapter explores the culture of hacking and its role in supporting engaging and meaningful educational experiences for diverse groups of learners. The discussion focuses around two case study examples. The first, KIDI, is an interactive museum exhibit that is located at a Fenton House in London, a National Trust property, and which repurposes interactive audio routines and hacked force-feedback controllers to facilitate engagement with a collection of keyboard instruments, the Benton Fletcher Collection, thus enabling visitors to learn about their sound and playing characteristics through play. The second, BitBox!, is an interactive gestural digital musical interface, which is designed to deconstruct and explain the underlying technical frameworks that support adaptive video game soundtracks and which draws upon a vocabulary of spatial and gestural controls from both video gaming and music performance. Both case studies highlight the importance of play as a vehicle for learning, harnessing both the physical and conceptual aspects of play to test and explore the limits of our skills and understanding.

**Keywords** Enactive learning • Learning through play • Gestural control • Hacking • Music education

## 4.1 Introduction

Learning music is difficult.

Musical expression and fluency depend not only on a player's technical ability on an instrument, a skill that requires both mobility and dexterity and that can take many months to master, even to the extent that the instrument of choice will make any kind of sound consistently without squeaking, but also on a knowledge of music theory and notation. Mastery of these, combined with the strong motivation to

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express oneself musically, can create transcendental musical moments that connect instrumentalists and audients powerfully, but conversely, they can act as barriers to entry and progression; novices often become demotivated and give up once they grasp the sheer amount of time and effort that is involved in learning to play even at a basic level (McPherson and Zimmerman 2002, p. 338).

And yet, the benefits of music-making are clear. While the purported impact of the Mozart effect has now largely been discounted (Bangerter and Heath 2004), active participation in music has tangible effects on wellbeing; it is mentally and physically stimulating, encourages the development of fine motor skills, and provides us with a unique expressive voice that allows us to connect with those around us (Coffman 2002).

Participation in music is also fundamentally linked with the notion of play (Richmond 2002), whether in the ultimate performance of a piece or in the way in which musicians explore the musical territory mapped out by dots on staves and their relationship with these as they learn new pieces and begin to shape what their ultimate realization might be.

This idea connects music directly with video gaming, which can likewise be a playful activity that is mentally and physically stimulating and that encourages the development of fine motor skills; the agility with which gamers link together complex sequences of keypad combinations to trigger a special move, for example, can be every bit as impressive as the fingerwork required to play a Bach Invention.

Video games such as *Guitar Hero* (2005) and *Dance Revolution* (1998) have become global phenomena by building on that link, connecting the innate human desire to make and respond to music with that for play, using custom gaming interfaces, guitar-shaped controllers or dance mats, to develop a combination of spatial awareness and a high degree of rhythmic precision in the players. While the technical skills developed while shredding in Guitar Hero might not translate directly to more traditional musical interfaces, that conceptual sense of rhythm and performance most certainly do.

This chapter, then, explores that point at which music and video game technologies converge. It is a collision of performance and play that opens up new ways of conceptualizing and engaging with music on many different levels. We'll begin by exploring hacking as a means of enquiry, briefly outlining its roots in the Tech Model Railroad Club at MIT, before showing how such technical play has afforded opportunities for the technically mediated exploration of music since the very beginning of the home computer revolution in the 1970s. We'll continue by looking at two case studies that demonstrate how different aspects of video game technologies, one hardware and one software, have shaped how people engage enactively with both music practice and music theory, building on centuries of tradition of learning about music through participation. We will conclude with a brief summary review of the underlying approach and suggest future directions that the crossover between performance and play might take music education and performance.

## 4.2 Music Hacks

The term ‘hack’ has its roots in the slang of MIT’s Tech Model Railroad Club. Its members had a permanent track layout in their clubroom, but while the track itself was impressive, a sprawling vista of meticulously crafted engines and buildings, it was nothing compared to the immaculately engineered matrix of relays and wires that lay beneath. The circuitry was the very embodiment of a hack, a project undertaken not solely to fulfil some constructive goal but for the sheer pleasure of learning about and carrying out the task itself (Levy 2010, p. 8).

This idea, of making playful exploration an end in itself, taps into a basic human instinct. It is how we all, as children, begin to make sense of the world around us and our position in it (Natanson 1997), and it is an approach that lies at the heart of many contemporary video games. Sandbox games and walking simulators, for example, which present the player with little beyond a loose game framework, a defined gameplay mechanic and the opportunity to explore, represent an interesting shift in the notion of what gaming is and how it is structured, shifting the responsibility for the creation of the game narrative and any meaning that might result onto the player. Even the name walking simulator, a tongue-in-cheek reference to the idea that in such games there is nothing prescribed except the walking mechanic and no goal save for discovery, embodies the notion that for such games to work, it is the players who must construct meaning from a blank canvas.

Much of the criticism around titles like the Chinese Room’s *Dear Esther* (2012), for example, focuses on the idea that these games aren’t really games. But while Dear Esther and the Chinese Room’s most recent game, *Everybody’s Gone to the Rapture* (2015), certainly challenges the existing conventions of video gaming (Heron and Belford 2015), they tap into a culture of exploratory play that has been part of home computing culture since the very beginning.

Early in 1975, Steve Dompier boarded a flight to Albuquerque to pick up a computer kit. The machine in question was an Altair 8800, and Dompier, like hundreds of other computer hobbyists who had seen the Altair on the cover of the January 1975 issue of Popular Electronics, was desperate to get his hands on one.

Thirty hours after returning home with the kit he had travelled interstate to secure, Dompier’s Altair was up and running. Dompier, though, faced a conundrum: What do you do with a machine that has no software, I/O boards, or peripherals? Simple. You hack some together.

Dompier powered on his machine and started to tinker with it. As he played around with different sort routines, he noticed that the long-wave radio that he had on in the background began making strange noises when he hit the run switch on the computer. Each time the Altair sorted a list of numbers, the radio started making pitched electronic tones; it was picking up the switching noise of the computer. After experimenting with different sections of code and timer loops, Dompier drew up a table of pitch values and wrote a short assembly program that used a series of counter loops to replay music entered as a list of numeric values. To test his new routine, Dompier grabbed the closest piece of sheet music he could find, a copy of the Beatles' *The Fool on the Hill*, and set about translating it into code (Dompier 1976).

At the next club meeting, Dompier set up his Altair and let it sing. The audience demanded an encore. In an act of digital showmanship, the Altair broke into its own rendition of *Daisy Bell*, a moment of creative subversion that Dompier described as 'genetically inherited', a reference to the IBM 704's performance of the song at Bell Labs in 1961 (Doornbusch 2009, p. 561), which, in turn, inspired HAL's eerie rendition at the end of Kubrick's 2001: A Space Odyssey (1968).

By hacking around with the Altair, Dompier was able to move beyond the documented features of the system and work laterally with the technology, an act of creative transgression that granted a new perspective on the hardware, allowing it to be applied, along with the repurposed transistor radio, in a way that, to the assembled crowd seemed like magic.

Sharing was a key part of the hacker ethic, forming the bedrock that supported the sort of inquisitive tinkering and exploration that hackers loved (Coleman 2013, p. 68). And so, almost as soon as a novel game or piece of software was released, hackers would be 'under the hood', finding out how the code worked, modifying and improving it, and sharing it within the nebulous community. Dompier published his code in Dr. Dobbs Journal and fully expected readers to modify it, using it as a jumping-off point to explore new music and new forms of musical expression: 'After the article was published, he recalled in a submission to the Homebrew@30 event, 'I received many phone calls as far away as India from people that wanted to play me the songs that they had entered into the Altair' (Digibarn.com 2016).

That is the true beauty of hacking. It is technology and discipline independent. It is about the craft of work and the process of exploration, about taking pride and finding joy in the process and technology and in understanding every detail of it. Through that affinity comes creativity and independence and from that the sort of creative linkages that lead to recastings of knowledge and reassociations of technologies. This is the real value of hacking. On every level, both through the process of hacking and the end result, it encourages learning through play.

## 4.3 KIDI: A Tactile Controller for Learning Through Play

In his foreword to the American Alliance of Museum's publication, Building the Future of Education (Robbins 2014), Michael Robbins, senior advisor for non-profit partnerships at the US Department of Education, describes the joy felt by his 6-year-old niece as she discovered a drawer on a display wall in a museum and exclaimed 'OOOOOHH! More information!'

Carefree encounters like this, which inspire a tactile and playful approach to learning and inquiry, do not just happen by chance. They require careful planning of the learning materials, the assets if you like, and the mechanisms through which that learning takes place. These are concepts common to game designers and something that the heritage sector, particularly in the last decade, has worked hard to embrace.

The Benton Fletcher Collection, a collection of historic keyboard instruments, is maintained by the National Trust at Fenton House in Hampstead as a playing collection. Comprising some 19 instruments, including harpsichords, spinets, virginals, clavichords, and pianos, which date from the late sixteenth century, it was established by Major George Henry Benton Fletcher, a committed collector who – unusually for his time – advocated the value of playing early music on the instruments for which it was composed. Benton Fletcher made his instruments available to music societies and students for tuition, concerts, and other cultural events, and, when the collection was gifted to the National Trust in 1937, he stipulated that the instruments should continue to be maintained for tuition and public performance (Waitzman 2003).

The National Trust is fully committed to this purpose and maintains a balance between Benton Fletcher's request that the instruments be played – music students can audition to use them, and visitors can attend 'playing tours' and concerts featuring the instruments – and their long-term preservation. However, because of limits on staffing and due to the fragility of many of the instruments in its charge, access is limited, and most visitors to the collection never get to hear or play them.

Of course, it is entirely understandable that the National Trust should err on the side of caution. After all, let a few cohorts of eager schoolchildren loose on a working sixteenth-century virginals, and the collection may not have a working sixteenth-century virginals for very long. And yet, without the opportunity to play with and on the instruments, visitors never get to experience the very thing that the instruments were created to do.

Providing opportunities for playful experiential learning is important. Sternberg argues that as we move through the education system, we lose some of that spontaneous creativity, becoming attuned to how the system works and adopting a more strategic learning approach in order to achieve formal learning outcomes as efficiently as possible (Jenkin 2013). And yet, outside of formal education, we never lose that urge for learning through creative play, motivated by our own enjoyment and entertainment. Witness the explosion in media sharing platforms for user-generated content and the novel use of social media for a very tangible example.

It is precisely this type of enactive learning, direct learning through association and experience, that is really the only way to engage meaningfully with whole classes of heritage objects, those that represent an emotive fusion of form and function, yet which are often displayed from within a glass case or from behind a red velvet cord.

It is one thing, for example, to look at and appreciate the design of a classic Ferrari 625 TRC Spider in an automotive museum and quite another to sit in the cockpit, turn over the engine, and depress the throttle, drinking in the sensory experiences as the car accelerates, feeling the tactile pleasure of the weight of the clutch and the steering, smelling the oil and the burning fuel, and, of course, hearing the roar of the engine. Very little compares with the impact and richness of this sort of direct experience. It is powerful and impactful, almost incommunicable.

In exactly the same way, it is as natural an impulse to press the keys of a Kirckman harpsichord, regardless of musical ability, to better appreciate the complex relationship between its mechanics and its voice. Such learning is entwined with the physical experience of play and of exploring the limits and sensations of the musician-instrument interface.

If we display musical instruments merely as objects, we strip them of their function. They cease to be objects in their own right and become visually compelling and ornate – but ultimately impractical – pieces of furniture. This limits our opportunity to interact with them and deprives us of the chance to become active agents in the formation of the narratives that allow us to learn about those aspects of the instruments that are so intimately bound up with their purpose.

It was precisely this curatorial problem – the red velvet cord problem – that the Trust sought to address through a process of gamification, creating a playable simulation using high-definition sound sampling mated to a bespoke hardware keyboard controller. This combination of hardware and software was christened KIDI, Keyboard Instrument Digital Interface.

As a means of fulfilling the Trust's remit for education and outreach, this approach has a number of advantages. Abstracting the elements of the collection that are of primary concern from an experiential perspective – namely, the sound and playing characteristics of the instruments – from those that present the biggest challenge to preservation (the fragile mechanisms) and embedding the sounds in robust, relatively cheap digital electronics allay many of the concerns about maintenance and preservation and so effectively give technically mediated license to the user to experiment and play with the instruments and their sounds in a way that would just never be possible on the originals. Collectively, these arguments provided the rationale to investigate the use of music technology as a means of accessing cultural heritage, with a particular emphasis on the visitor experience and how it meets the needs of the twenty-first-century heritage tourist to be 'entertained, stimulated, [and] emotionally and creatively challenged' (Leighton 2010).

The core methodological approach for the project dates back to 2003 and evolved in response to a sound production problem.

The author sought to create a set of archive recordings of the Panmure Music Collection (National Library of Scotland), which comprises some 30 volumes of music, with 12 dating from before 1675. Much of the music is Scottish and English in origin, but the collection also includes 11 volumes of French music brought back to Scotland by James and Harie Maule between 1678 and 1683 and six volumes of opera scores and parts acquired by James Maule while in exile in Italy after the first Jacobite uprising in 1715. The historical significance derives from the music's timeline: it captures the emerging sound of the Scottish art and courtly music of the early Jacobean period just as its development was stifled as the Scottish Court – and its patronage – moved to London following the Union of the Crowns. The manuscripts were rediscovered in the 1930s and placed by the Earl of Dalhousie in the trust of the National Library of Scotland, where they remain on permanent loan.

Much of the music had never before been committed to recording and exists only in the form of archaic handwritten manuscripts. There is, of course, a world of difference between reading a manuscript and hearing the music performed. In the same way that the transcript of a rousing and emotional speech cannot hope to capture the passion of delivery, so too a musical score is at best an approximation of performance, and so to bring these compositions to life and appreciate them fully, it was necessary to transcribe the manuscripts and create a set of archive recordings.

Few keyboard instruments survive unmolested from the early-mid-seventeenth century, and fewer still are in good playing condition. The project team was granted access to a Kirckman harpsichord, dated 1776, which is held in trust at Hospitalfield House in Arbroath by the Patrick Allan-Fraser of Hospitalfield Trust. Although the instrument was from a slightly later period than the manuscripts, there was evidence to suggest that it was of a similar design to those for which the keyboard music was written. It was of the right type – the Kirckmans were one of England's foremost manufacturers of harpsichords (Waitzman 2003) – and it was in original playing condition. However, it was not suitable as a recording source. The soundboard, in particular, had warped and cracked, as shown in Fig. 4.1, causing problems both with stability of tuning and with note articulation.


**Fig. 4.1** Warping and cracking of the Kirckman's soundboard. The main damage can be seen up and to the left of the serial number, below the nut

The response was to create a digital simulacrum of the instrument, using a customized combination of hard disk streaming for the sound source and 3D-spatial audio modelling for the body resonances and simulated room ambience, to overcome those mechanical issues that would be costly to repair, both financially and curatorially.

It is important to note that any sampled instrument is fundamentally different from an acoustic instrument. The former is composed of a finite number of static snapshots, recorded at a particular moment, whereas the latter is, in principle, infinitely variable with a character and subtlety of expression that depends as much on the environmental conditions in which it is played as it does the manner of its performance. As such, it is impossible to create an exact digital duplicate of an acoustic instrument. However, by careful application of recording and editing techniques, it is possible to mask these digital artefacts, particularly in a performance context, to the extent that it is difficult, under normal listening conditions, to tell apart a recording of an acoustic instrument and a recording of a digital simulation of an acoustic instrument.

Initially, then, the work with the Kirckman was used to focus on those aural cues that are necessary and sufficient to trick the ear into thinking that it is listening to an acoustic performance. The solution, it transpired, is very much context dependent and best specified as a production approach. The approach is both analytical, in that it first focuses on a detailed analysis of the instrument and those idiosyncrasies that give it its unique character and sound before selecting a recording strategy that allows the samplist to capture those sound-producing elements independently, and reflective, in that the recording and editing chain must be carried out with one eye on the end user and the other on a series of reference recordings of the original instrument to ensure that the individual layers of the digital instrument combine to provide a listening experience that is close to the original.

Such elements as instrument tone are relatively easy to record, but special care must be taken with other subtler elements of the sound, such as the transient attacks, which can vary depending on the velocity of the note and which are important in simulating fast-repeating notes without 'machine-gunning' – an artificial mechanical-sounding effect that occurs when repeating a small number of note samples is played back in quick succession and named for the effect in a shoot 'em up, where repeated playback of gunshot sounds betrays the limited source material in the recordings; key release noise, which is release-velocity dependent and very important in creating the illusion of realism; sympathetic resonance; and mechanical noise. The precise make-up of the sampled instrument will necessarily vary depending on the particular characteristics that make up its sound and the prominence of each, but as with a good director of photography on a feature film, who will include only enough visual detail within each frame of a film, using depth of field and motion blur to bring key elements of the frame into focus and push others into the background, so too a samplist looking to recreate the specific sound of an instrument will first analyse the component parts of its sound and construct the digital model so that those which are most prominent feature are the key aural cues, while the others provide layers of supporting detail.

The resulting instrument was used as the basis for a series of instrumental recordings (McAlpine 2005a), and the process and outputs were exhibited at an international exhibition of digital heritage and preservation at Belgium in 2005 (McAlpine 2005b).

This, then, provided the main means of capturing and modelling the instruments in the Benton Fletcher Collection, which served as the central sound source for a dedicated interactive exhibit at Fenton House, allowing visitors to the collection to access and play the instruments in the collection with no risk of damage to the originals. At present, digital models have been created for nine of the instruments in the collection, and plans are in place to model the remaining instruments in the coming years.

The audience at Fenton House is diverse and multigenerational, and the design of the interface necessarily had to cater for multilingual, multicultural, and multigenerational users. As Chitiz Mathema discusses, it is '[t]he holy grail for both users and developers [to create] a user interface that most effectively and intuitively leverages the most relevant senses [ . . . ] into the most optimal user experience' (2014).

A single-touch touchscreen interface was selected as the most appropriate mechanism to provide control over the instrument's navigational interface, drawing heavily on the approach to interface design now commonplace in casual games on mobile devices. Physical single-touch buttons are near ubiquitous, and so the single-touch screen, which provides a tactile digital equivalent onscreen, creates a clear cognitive link with a familiar method of 'real-world' control. The main screen, therefore, presents a series of pictorial navigation buttons that allow users to select instruments and navigate to a performance page, which presents contextual information about the selected instrument, loads the soundset associated with that instrument, including all performance variations, and presents the user with a set of touchscreen controls, a direct equivalent of the mechanical stops, which allow real-time control of these performance variations.

The control surface is a two-manual MIDI keyboard, which uses two semi-weighted single-manual MIDI keyboards, with modified keybeds and scan circuits to replicate the layout of the harpsichord keyboard, commonly, five octaves from F to F, with no F♯ in the bottom octave. Keyboards from the collection whose span is shorter than five octaves are accommodated by leaving some keys in the keyboard unmapped and short octaves – a means of assigning the most common notes to the bottom octave of a keyboard to extend its range – by a simple remapping of the root pitch. Broken octaves, a variant of the split octave which increased the bass range by means of split keys, required more of a compromise, since there was no cost-effective means of producing a split-key electronic keybed, and an alternative approach that used a foot pedal as a means of real-time keyswitching was adopted, this being both a natural performance gesture in keyboard performance and also very much in keeping with the notion of the harpsichord machine stop, a foot-operated pedal that was used to mechanically alter elements of the instrument's setup in real time (Hubbard 1967).

The MIDI keyboard acts as a front-end interface for an embedded PC running the control software and handling sample playback. All of the componentry is housed

**Fig. 4.2** The two-manual MIDI interface for the digital harpsichord

within a bespoke transparent Perspex casing, illustrated in Fig. 4.2, which allows visitors to see all of the electronics, making a display feature of the digital nature of the instrument and properly delineating it from the other instruments within the collection.

Between 2008 and 2013, four iterations were made of the modelling process, as new instrument models were added, and existing models were refined following both end-user and expert feedback. The response from the end-user group was broadly positive and supported overwhelmingly the notion of virtual access to the instruments in the collection; in particular, comments, gathered from face-to-face interview and from a visitors' book, indicated that the endorsement of the National Trust proved to be more important to the end users' perceived authenticity of the sound than the instrument models themselves. This does not necessarily suggest that the latter isn't an important consideration, but it does, perhaps, give us an insight into the conditions under which visitors will willingly ascribe authenticity to the experience of playing virtualized heritage objects.

That notion, however, of experiential authenticity, was the one major area of concern for the expert user, who noted that she felt detached from the sound source because the key action lacked feel.

The feel of an acoustic instrument is of fundamental importance to musicians. They train for many years to achieve the fine motor control necessary to coax the full range of expression from their instruments. Any performance is the result of a complex dynamical system which incorporates gestural input from the player, the mechanics of the instrument, and the resonances and natural amplification that its body provides. However, there is no straightforward mechanical solution to this problem. There is no commercially available keybed that will replicate the feel of an antique harpsichord, and, although it would be possible to fabricate a 'dummy' mechanical mechanism, similar to the piano mechanisms used by, for example, Kawai, Roland, and Yamaha in their high-end digital instruments, the approach would be prohibitively expensive and does not represent a workable solution for two key reasons.

Firstly, although mechanical key actions can be engineered to provide an accurate key feel for a particular instrument, a grand piano say, or a clavichord, that same action will be rendered inappropriate as soon as a different soundset is loaded. The experience of playing, for example, a positif organ with a piano mechanism is disconcerting and inappropriate: composers wrote for the music technology that was available to them at the time, and the fast scalic music of the harpsichord was as much a function of the light and delicate action of the instruments as it was the fashion of the time. To truly appreciate and understand the instruments and their musical context, the way the instruments play and respond to the player must be at the core of the experience.

Secondly, from a heritage perspective, where, as we have discussed, the aim is to achieve a form of 'experiential authenticity', there is also a much more stringent threshold than 'good enough' – it is not sufficient to create a mechanism that is generically appropriate to the instrument class, but to create, on a key-by-key basis, the precise mechanical feel of an entire keyboard.

Similar issues can be found in gaming. In the very early days of home video gaming, game controllers, the tactile point of interface between gamer and game, were limited. The Atari VCS, for example, offered players a choice of paddle controller or joystick, drawing on the conventions established in the arcades, with home computer platforms also offering the keyboard as a controller. Although novel controllers, such as the plastic surfboard that sat on top of the computer keyboard to control an electronic surfer in *Surf Champ* (1985), made it to market, they were largely single-application modifiers of existing controllers and failed to have much impact beyond the title with which they were bundled.

Those traditional controllers, however, except in a few cases, represented compromises, and the design of video game mechanics focused largely on devising a control system that mapped the limitations of the available controllers to the dynamics of the gameplay. These compromises were most evident in games that required subtlety of control, driving games and flight simulators, for example, where the binary response of a keypress or a digital joystick could not hope to capture the fine motor inputs necessary to correct a drifting race car or to yaw an aircraft into the wind. It is a rare situation, even on a racetrack, that calls for a driver to move instantaneously from full lock to lock repeatedly and yet with a traditional digital joystick controller that was the routine for the gamer.

From the late 1980s onwards, specialist controllers started to enter the marketplace, beginning with analogue joystick controllers and moving through steering wheels complete with gear sticks and pedals through to full hydraulically controlled ride-in cockpits offering multiple dimensions of force feedback, as both developers and end users recognized the value in designing control interfaces that not only replicated the look and layout of the physical systems they were trying to simulate but which also used touch as a key point of user feedback.

This is the point of convergence that provides the solution to this problem. Those same tactile and force-feedback video game controllers that were once single-purpose novelties, often hacked together in the hobbyist community, have become the mainstream, meaning that very sophisticated but low-cost tactile and gestural input devices are now available and, crucially, very hackable: the ubiquity of the internet and the inquisitiveness of its users provide a shared knowledge base, a technical repository that covers the detail of how virtually every commercial electronic device might be disassembled, modified, and creatively misused.

As a result, hardware and software have been repurposed and redeployed for all sorts of cultural and educational ends, particularly where the gaming technologies at source support multimodal interaction, social inclusion, and a strong, defining narrative, all elements identified by Klimmt as key features of a successful serious game (Klimmt 2009). Guitar Hero, for example, has been used to support schoolchildren at key points of educational transition (Jindal-Snape et al. 2011), and Nintendo Wiimotes have been hacked and used for purposes as diverse as music-making (Qin 2012) and armed response training for police (Robertson 2011).

The solution for the KIDI draws on that approach, adapting the simple sprung action of the MIDI keyboard to introduce a series of linear voice coil actuators, each with integrated positional sensing, to provide fine-motor force feedback. As the player depresses the key on the keyboard controller, the position sensor, which can operate to a resolution of 10 microns, tracks the key travel and compares the keystroke to a sampled model stored in memory. This, in turn, allows for very precise control of the response of the voice coil actuator, making it possible to quite accurately simulate key feel on a note-by-note basis and providing a computationally efficient way of storing a modelled tactile response alongside the instrumental sound models. In practice, this means that a single hardware game-derived controller can function as a multi-touch keyboard, one that adapts its playing characteristics to accurately mimic the feel of the soundset that the user selects from the software interface. This represents a development of earlier work by Brent Gillespie at Stanford University, whose Touchback keyboard used simplified kinematic mathematical models of a grand piano action and motors originally designed for large disk drives, an approach firmly grounded in video game dynamics and hacking, to similar effect (Gillespie 1996).

## 4.4 BitBox!: A Gestural Framework for Exploring Adaptive Music

This approach, that of adapting technologies in different contexts and using them as a platform to learn about music and its development through exploratory play, can also happen at a structural level, and that is particularly important when considering forms of music that challenge our established notions of what music is and how it functions. Just as games like Dear Esther force us to reappraise video gaming, the soundtracks to those same video games, which must adapt in real time to player input if they are to accurately capture the narrative contours and emotional peaks and troughs of the gameplay, challenge our notion of what music is and also our approach to its creation and performance.

The University of Abertay currently delivers a number of creative computing degree programmes focused on the computer games industry. One of these, a Bachelor of Arts in Sound and Music for Games, concentrates on the content creation of digital sound and music assets and their implementation, analysis, and evaluation. The programme launched in 2006, and, in the years since, it had become clear that while many students have a very keen sense of musical awareness, a good contextual knowledge of contemporary video games and the gaming industry, and well-developed composition skills and were keen to study music composition for games, very few of them had any real conceptual understanding of the structures and processes that underpin real-time adaptive music or how to approach the problem of scoring for interactive media: writing music whose form and structure will change depending on user input requires a different mode of thought to writing music that adheres to a more linear structure and that presents a significant learning challenge.

This, perhaps, should not come as too much of a surprise. Game Studies, the field of study that focuses on game design, players, and their role in society and culture, is a relatively new and evolving discipline (Williams 2005), and the study of the subfield of game music is yet more nascent. As a consequence, there is a limited repertoire and critical discourse from which to draw, and tutor and learner may have few mutual points of connection in discovering and understanding the musical drivers, relationships, and structures in these works.

For the video game composer, the structural methods that have become standardized through development tools like those of FMOD and Wwise impose constraints on the way music is written to work with them. Composers often have to write game underscore 'blind' to provide feedback on game states that cannot be determined in advance and must consider the different ways that one section of music might transition into another, perhaps using techniques such as tempo or key matching, that is, writing contrasting sequences in parallel at the same tempo and in the same key, to ensure that such transitions can be made, if not seamlessly, at least without losing musical coherence.

Compositionally, it is similar to a very complex and technologically mediated game of *Musikalisches Würfelspiel* (Sweet 2014, p. 111), but for students to properly appreciate the subtleties and implications of this, they must first understand the structural edifices of adaptive music and how these work, both individually and in combination. As with learning to play an instrument, which is something that can only effectively be done through the practice of performance, so too, learning to compose is a skill that depends fundamentally on process; while it is possible to learn and appreciate the underlying compositional theory, one can only learn to put it into practice by putting it into practice.

The challenge is in designing a classroom experience that allows for a student group, who have a shared sense of purpose and vision, but a very diverse range of musical abilities and experience, to explore the different elements of adaptive music in a way that is accessible yet significant and, crucially, which allows them, through play, to explore and challenge the boundaries of their knowledge, skills, and understanding and thus challenge their notion, through experience, of what music is and how it works.

Partly this is an issue of interface: choosing, for example, a keyboard interface as the primary means of interacting with music, excludes by design those who don't have that particular set of music performance skills. Partly, it is an issue of dealing with convergent skill sets: adaptive music of this sort depends fundamentally on an underlying technical framework, the development of which requires a complementary set of skills that is separate from those normally developed on music performance or production courses.

This notion of the video game composer as being someone who operates at the nexus of coding and performance goes back almost as far as video gaming itself. Pete Samson, for example, an early computer music pioneer at MIT, not only developed an early music compiler that allowed electronic musicians to perform music as a sequence of alphanumeric characters but also helped create Spacewar on the PDP-1, widely acknowledged as being the world's first shoot 'em up (Graetz 1981).

The video game composer Ben Daglish, who, even now, some 30 years after he last wrote a line of music in 6502 assembly, is recognized for his contribution to the development of the style, emphasizes the importance of both aspects. 'That job', he says, 'programmer-musician, was quite a niche one, and it had a very limited life. I mean there was me, Rob [Hubbard], Martin [Galway] and Dave Whittaker, and that was it. We were the four full-time Commodore guys in the country. We invented the job of computer musician, which is something I'm still proud of. In total, it lasted maybe 15 or 20 years, if that. But it was a unique crossover where you had to know quite a lot about both the creative and technical aspects. It wasn't just writing music, it was programming it as well'. (McAlpine 2015)

For students without that technical know-how, this also serves as a barrier to access. As Marie-Laure Ryan notes, 'Not many of us prefer writing plays and novels to watching and reading them; by the same reasoning, most users of interactive narrative systems prefer being invited into a story than having to create it from ground zero' (2011). By extension, most of my students would much rather just write the music rather than have to worry about the tricky detail of how it works. The inconvenient truth, however, is that in a video game context one cannot be achieved without the other.

Our natural tendency is towards a curated experience that encourages and supports the formation of meaning and significance, rather than unstructured complexity from which meaning and significance must be painstakingly extracted. This is what the very best games manage beautifully; they make the conceit of the game transparent, and the mechanics and the interface work together to allow the gaming experience to flow. That, surely, is a goal of educators too, to provide experiences that encourage learners to form meaningful associations and embed layers of understanding without the clunky mechanics of learning being obvious to them.

BitBox! was created as one such learning tool. It is a gestural adaptive musical instrument that deconstructs the different elements of video game music tools and presents them in a form that allows learners to explore them and play with them either individually or in combination.

While traditional acoustic instruments have layouts, interfaces, and modes of interaction that are largely determined by their physical properties, electronic instruments, which break the direct physicality of sound production by isolating the front-end control interface of the instrument from the back-end tone generation and audio output, are not constrained in the same way. Anything that can be digitally captured and encoded can effectively be used to control and shape musical performance.

Such flexibility in design capability raises interesting questions about its application in musical interfaces and, since there is no single permitted set of options, how best to balance complexity and subtlety of control against user agency and the learnability of the instrument.

Much of the relationship between performer and instrument and between performer and listener is embodied in a series of gestures. As Goldstein notes (1998):

> Music is a performing art, and part of the quality of the musical experience comes from the relationship between the player's physical technique and the sound that is produced. A listener can appreciate this connection visually (and viscerally) whether in a live concert or in the mind's eye while listening to a recorded performance. Our rich tradition of musical instruments has created a repertoire of gestures (bowing, blowing, banging, etc.) that are closely tied to familiar sounds.

The arrival of Nintendo's Wii in 2006 revolutionized gaming by allowing gamers to interact with and control games using their own natural movements in space (Felicia 2014, p. 198) and went some way to normalizing the idea that gaming interfaces could be physical extensions of the game space controlled by metaphorical gestures that relate directly to the in-game actions they seek to control. Recent advances in the size, power, and cost of microcontrollers and sensors mean that it is similarly possible to rapidly prototype bespoke interfaces that capture and encode spatial gestures and body movements relatively easily and use these to control electronic musical instruments.

There is an issue, though. Recall that one of the reasons for not simply duplicating an existing traditional musical interface was that while it provided a continuity of experience for those already fluent with that particular interface, it excluded others who are not. Exactly the same issue holds for a gestural interface, although its novelty does level the playing field somewhat. Unlike graphical user interfaces, whose key strength lies in making visible and, thus, through exploration, discoverable, the possible gestural interactions a user might have with a system typically have to be learned, and often they require practice to refine and control. Donald Norman emphasizes the fact that while gestural control systems offer interesting potential for interaction and control, they are no different from any other form of interaction and should provide well-defined modes of expression, a clear conceptual model of the way users interact with the system, and the consequences of their actions. (Norman 2010). This contrasts, perhaps, with many recent gestural instruments, whose design is tailored to the needs of a particular performer, looking to translate their personal language of gesture into sound (Rovan and Hayward 2000).

The challenge, then, was to design an interface that was transparent and intuitive yet nuanced enough to afford detailed control. As such, there was an identifiable need to keep the gestural vocabulary simple and to employ gestures that resonated with the user's conceptual model of the instrument and their interaction with it.

It is not uncommon, particularly in the first-person shooter genre of games, for proximity to be used as a control driver for game music, with the soundtrack changing as the player moves between game zones or closer to danger or an end-of-level boss. Proximity, then, seemed to provide a sensible basis for a gestural metaphor, since it provided a clear conceptual link between the instrument and its game music analogue, and had a clear music performance precursor in the Theremin.

Invented by Léon Theremin in 1919, the instrument uses near-field capacitance as the basis of tone control, with the player moving his or her hands in close proximity to two antennae, generating a constantly changing capacitance. The player's right hand controls pitch and the left amplitude. The gestures are natural and easy to understand, but playing the Theremin is notoriously difficult, since pitch, in particular, is very sensitive to hand position, and, since hand capacitance approximately follows an inverse-square law, pitch sensitivity increases the closer the player's hands get to the antennae. Further, the instrument provides no tactile, only auditory, feedback, which requires a very high degree of coordination between the player's aural and motor skills (Glinsky 2000).

To address the issue of the sensitivity of nonlinear response, ultrasonic proximity detection was used in place of hand capacitance. Ultrasonic sensors are now well established in noncontact presence, proximity, or distance measuring applications and are available as modular components that are easily incorporated into prototype circuits and can be configured to provide linear output either digitally or by means of a continuously variable analogue voltage (Massa 1999).

A network of ultrasonic sensors was designed to interface with a central controller module comprising an Arduino Uno microcontroller and a small breadboard, which distributed the +5 V power signal, provided a common ground, and routed the analogue return signals from the sensors to the appropriate inputs on the Arduino. A custom Arduino sketch was written to sample the continuous analogue output streams from each ultrasonic sensor in sequence, with a 25 ms delay between each to minimize the effects of crosstalk. The input data were converted into MIDI control messages and transmitted via USB to a host computer to control a 3 min looping adaptive music track via custom program scripts.

Initial testing was carried out with a class of 25 undergraduate students, before the full BitBox! installation was presented at Dare ProtoPlay 2014, an international games expo, which ran from the 7th to 10th of August in the Caird Hall in Dundee.

**Fig. 4.3** The Bitbox! sensors were mounted on wooden plinths in the centre of the space and arranged to minimize crosstalk between sensors. A 42″ LCD screen was mounted at the rear of the space to provide a real-time visualization of the music

The event attracted 13,000 visitors. The main audience (approximately 42% of the total) came from the 15–25 age group, providing a good representative sample of the target audience for BitBox! The instrument was enclosed in a $3 \times 4$ m space, with the sensors mounted on wooden plinths placed centrally within the space and arranged to minimize sensor crosstalk, as shown in Fig. 4.3. A real-time sound visualizer was used to generate synchronous imagery that was displayed on a 42″ LCD screen to the rear of the space. The control module, the host computer, and an amplifier and speaker were hidden from view at the rear of the presentation space.

The response to the instrument at the event was overwhelmingly positive. After a brief period of tentative exploration, very quickly users adopted a confident posture and moved their hands purposefully and expressively, mimicking the stance and some of the gestures of an orchestral conductor, suggesting that users very quickly felt a real sense of musical agency through their actions and had the confidence to playfully explore the creative space set out by the instrument. It also suggests an avenue for the future development of the interface, drawing on the rich vocabulary of conducting gestures to expand the opportunities for interaction and expanding the controllability of the system.

One interesting consequence of the simplicity of the gestural control system was that it facilitated multiuser interaction. Users reported that their experience was improved by using BitBox! with others and that they felt confident and uninhibited using the system collaboratively, even with strangers. Multiuser interaction was entered into enthusiastically, suggesting, perhaps, that a simple expressive music interface might have a role to play in overcoming performance anxiety issues in ensemble playing, where early stage musicians, particularly if improvising or inventing, feel constrained by their perceived lack of technical or expressive ability on their instrument, which often impacts on performance and sets up negative reinforcement of the idea that they are just ‘not much good’ at playing in groups.

## 4.5 Conclusion and Future Development

As a method of creative enquiry, hacking is a wonderfully liberating approach that encourages an inquisitive and playful relationship with technologies and their application. It is an approach that has gained real momentum over the last few years, with organized hackathons and music hack days springing up and offering opportunities to play at the boundaries of both music and gaming technology and offering a glimpse of how we might organize and experience music and music education in the future (Jonze 2009).

It is an approach that also has a proven track record in industry. Gunpei Yokoi, for example, the Nintendo product design engineer responsible for both the Game and Watch series and the Game Boy, practised a design philosophy that he called ‘lateral thinking with withered technology’ (Tobin 2013). He would take cheap, well-established and well-understood technology and use it in novel and innovative ways, not only making development more cost-effective and the development process less technically challenging, but, because the limited capabilities of the hardware provide the intrinsic motivation for the innovative use of the technology rather than on providing a platform to showcase it, it is an approach that better supports innovation itself (Warren and Jones 2008).

The core of Yokoi’s design philosophy has its roots in DeBono’s principles of lateral innovation (DeBono 1968). While most products are the result of iterative design, an evolutionary process that leads to the gradual refinement of the product over several generations, lateral design catches us by surprise, arriving seemingly from nowhere and perhaps solving a problem that we didn’t even know existed. Often it’s a result of approaching a concept obliquely. Just think of the Nintendo Wii; before it arrived, nobody knew how much they wanted intergenerational casual gestural video gaming, but just 5 min with Wii Sports convinced everyone, including rivals Microsoft and Sony. With the addition of a couple of cheap accelerometers to a handheld wireless controller, Yokoi’s lateral thinking with withered technology gave us all a new way to game.

Now that video game technologies, both in terms of hard- and software, have matured and become mainstream, they provide a cheap, well-tested and well-established set of hardware and software tools that are also recognized and understood by the general public. As such, they represent ideal technologies for hacking, particularly for those end results that might incorporate an element of play.

For both BitBox! and the KIDI, this synthesis of technology and ideas provided solutions to existing problems, on the one hand, how museums manage the meaningful educational access to their collections, and on the other, overcoming the initial technical barriers to learning about interactive music. In both situations, these hacks also suggested solutions to other challenges. The KIDI, for example, made accessible to visitors with impaired mobility those instruments that were located in inaccessible parts of the National Trust property at Fenton House, and several visitors to Dare ProtoPlay who had music therapy backgrounds suggested that BitBox! had real potential as a device for enabling meaningful and significant musical self-expression for individuals with limited mobility or dexterity.

That is precisely the direction in which future development of BitBox! is headed. Those same challenges that make learning interactive music difficult for undergraduate students hold true, indeed, are amplified, for users with mobility or dexterity problems, which might include older users and those with disabilities. For those who have been skilled musicians in the past, the onset of impaired mobility can have a catastrophic effect on wellbeing, since, among other things, it silences an expressive voice that was previously a central part of their personality and make-up. Similarly, for those who wish to learn, it presents a barrier to access and can limit both the rate and depth of achievement. Limited mobility does not diminish our inner musical voice or desire to express, but it does limit our ability to articulate them.

This is where technology has a role to play, in augmenting and enhancing whatever physical movement is possible to connect the musical ideas of the performer directly with the experience of play. And this, of course, is what gaming does best. So while these case studies present examples of the applications of aspects of video game technology towards serious ends, the means by which they achieve that end are where the notion of gaming has had the more profound impact. Games remind us that play can be fun, fulfilling, and absorbing. It can make us receptive and aware, and it provides us with a tool to test and explore the limits of our skills and understanding, in turn building confidence. By applying those principles to music-making, we can use the point at which performance and play meet to similarly build expressive confidence and fluency and a deep, contextual musical understanding.

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# Part III
# Games for Medical Education and Training

# Chapter 5
# Digitisation of Anatomical Specimens and Historical Pathology Specimens for Educational Benefit

**Paul Rea, Daniel Livingstone, Ianto Thorvald Jocks, and Cecilie Osnes**

**Abstract** In this paper we describe the scanning and digital development of anatomical and pathological specimens through trialling a variety of software packages and approaches to the creation of a digital record. Medical museums have traditionally been something that has not always been accessible to the wider public for a variety of reasons. The traditions within medicine and the science of the human body have typically not always been able to be accessed to members of the public. However, digitising artefacts is becoming more common, and this can enable wider access to scientific information to ensure people are more fully informed about the body and its processes and the rich history of medical science. As such, we present here a variety of means to digitise anatomical and pathological collections of historical specimens of international cultural significance. We present here the challenges with imaging these types of specimens and offer solutions to a range of challenges faced in the scanning of specimens. The use of digital specimens and their integration into learning and teaching is also considered. This should provide a research-informed and research-led approach to enhance the creation of digital assets for use in online museums and digital games, not just for the anatomy and pathology fields, but that of the wider museum community involved in engagement of a variety of different audiences.

**Keywords** Anatomy • Digital museums • Pathology photogrammetry

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## 5.1 Introduction

Recently, there has been a surge in the popularity of digital museums, whereby exhibits can be viewed online. New visualisation techniques have been employed to allow a wider engagement with archival and museum collections. Indeed, interactive exhibits of digital objects have resulted in some fantastic results for heritage management, especially with larger and less accessible items in a collection, or indeed ones that are more of a fragile nature. This digitisation of historical items has resulted in a more inclusive approach to public engagement and also improves the impact of collections through wider dissemination of artefacts.

Medical and anatomical museums provide a valuable insight into the history of medicine, as well as for enhancing anatomical education, both of the past and also for the present day. However, anatomy specimens by their very nature are incredibly fragile and can suffer deterioration through the passage of time. Therefore, digitally capturing these specimens will preserve them in a format with great longevity and may help overcome the negative impacts of wasting and damage and improve accessibility where specimens are locked away and not always available to the public in displays. Once digitised, specimens can be displayed through online museums or integrated into training packages and games.

At the University of Glasgow, there is a collection of anatomical and pathological specimens, some of which have international significance coming from the Hunterian and Cleland collections. Some of the historical specimens date back to the 1700s, and as the collection is so large, display of these in limited space is not feasible. Here in this chapter, we shall present two studies: one which has created digital educational material of prosected anatomical specimens and one of historical pathology specimens, to allow engagement with these items in a fully interactive means. This will enhance the outreach of these specimens and brings those in storage to the forefront in anatomical and medical education.

In addition, to preserve specimens, enhancing the global reach and enabling access, medical museums have an excellent opportunity at this moment in time to harness technological advances to image capture their collections. Novel techniques are already employed for digital imaging and archiving archaeological remains. However, comparative studies examining the pros and cons of different methodologies for creation of virtual museums are difficult to find. Therefore, the purpose of this study is to examine the use of photogrammetry, a commonly used technique for image capture for 3D visualisation. Specifically, we want to compare different software packages and approaches to create the virtual object. This chapter is therefore divided into two main parts. The first part examines the use of photogrammetry, the object virtual reality and the creation of interactivity via PDF files. The second component to this study will examine three key software packages that can be used when digitally constructing images from photogrammetry, comparing and contrasting them.

The first study to be presented is based on the creation of anatomical specimens in digital format using photogrammetry, object virtual reality (object VR) and the resulting creation of a fully interactive PDF. The workflow methodology will be presented in relation to the creation of an interactive PDF, as well as details of how anatomical and historical commentaries were integrated into these documents. This has resulted in the creation of interactive digital learning resources of typical specimens used in day-to-day teaching of anatomy.

The second project will present how to image capture internationally significant historical pathological specimens from Dr. William Hunter, an eminent anatomist and obstetrician from the 1700s. These specimens are in glass cases, some containing fluid. Using three different software packages (Autodesk ReCap, Autodesk Memento and Agisoft PhotoScan), we shall present a comparison of different imaging techniques to build on the knowledge of the best way to capture these types of specimens digitally.

We focus on photographic techniques. Alternative methods of digitisation include laser scanning – which can produce very high-quality digital models but which relies on relatively expensive specialist hardware – and the creation of 3D models from medical scans such as CT or MRI. The latter can be used to produce volumetric datasets – a series of 2D images representing “slices” of a portion of a body or object. CT and MRI are not considered for the current work for several reasons: they have a high relative cost, current CT and MRI techniques produce images at a relatively coarse resolution resulting in poor surface detail for volumes created from the slices and no object colour information is captured resulting in a total loss of surface texture information. While medical scanning has the notable advantage of being able to image organs and features internal to the human body, this is not necessary for the current work where all specimens have been previously dissected and prepared for visual presentation.

The workflows presented here will thus inform those involved in the creation of digital training and education packages of historical specimens as to the variety of methodologies which are available. This will also be correlated with learning and teaching theories about wider public engagement and enhancement of the student learning experience.

## 5.2 Photogrammetry and Object VR for Visualising Anatomical Specimens

To identify the most appropriate method of image capture to digitise an anatomical collection, several types of specimens were used to assess the best technique. To enable anatomical specimens to be incorporated into gaming technology, we first have to find the most suitable technique to be employed dependent on the nature of the specimen. Therefore, seven specimens were identified (of renal and cardiac anatomy) which were selected from the local collection in the Laboratory of Human Anatomy at the University of Glasgow (Table 5.1). The specimens were a mixture of wet (stored in jars, in liquid), dry (stored in jars) and plastinated (dry, preserved) specimens demonstrating typical and also atypical pathologies and comparative and human anatomy specimens.

**Table 5.1** Historical and modern renal and cardiac specimens

| Specimen number | Description | Nature of specimen |
|---|---|---|
| *Hunterian 10.19* | Heart at ca. age 12 | Wet specimen |
| *Cleland C.18* | Heart with opening in interventricular septum | Wet specimen |
| *Cleland C.9* | Heart with patent foramen ovale | Wet specimen |
| *Cleland G.27* | Right kidney with six separate renal arteries | Wet specimen |
| *Modern renal specimen* | Kidneys with sections of the abdominal aorta and inferior vena cava | Wet specimen |
| *Cleland C.5* | Heart of a harbour seal | Dry specimen |
| *Prosection 06–07/22* | Heart in the mediastinum | Plastinated specimen |

In undertaking photogrammetry of these specimens, a Canon EOS 600D digital camera was used with a 50 mm lens with the semi-automatic “panorama” and “no flash” settings chosen. The images were then converted from Canon-specific raw image format (CR2) to TIFF files and processed using Agisoft PhotoScan Standard Edition (Version 1.0.2 build 1984; Agisoft LLC St. Petersburg, Russia). Images were then created in the Unity3D (U3D) format. Post-processing of object VR images was done using Photoshop CS6 (Version 13.0.1; San Jose, CA, USA). Virtual reality (VR) movies, in flash format, were made in Garden Gnome Software Object 2VR Object Movie Creator (Version 3.0 Revision 4.8.3; Vienna, Austria).

### *5.2.1 Results of Photogrammetry*

Photogrammetry of the plastinated specimen yielded the best result with exceptionally high-quality images created. There was a minor area of deficiency where a “hole” was identified in the images (Fig. 5.1), but this was easily remedied by closing features within the software. In addition to this, dry specimens were also relatively simple to reconstruct. There were some minor drawbacks though when the specimens were contained in jars. Namely, where the jar was labelled, the software anticipated this to be part of the specimen itself. In addition, there were small areas where some of the anatomy may have been distorted due to structures having close proximity to other parts. However, no issues were found in relation to reflection of light through glass, and this would make this ideal for resin cast material or varnished organs.

Specimens that were wet (encased in glass, in fluid preservative) did, however, pose significant problems. Due to the preservation fluids, images were often distorted and the top and bottom of the specimens were not ideally visualised.

**Fig. 5.1** Photogrammetry of the heart within the thoracic cavity. The *arrow* highlights the area of the "hole" that was closed within the software

### 5.2.2 Object Virtual Reality

Images that had been post-processed were then imported into object VR. The purpose of this was to ensure a high level of interactivity and enhance the learning experience when viewing the images of the specimens. It was important to be able to rotate through a central axis but also to be able to zoom into the specimen to identify finer detail. In addition to this, the "hotspot editor" function was used to be able to display names when the mouse hovered over certain structures. PDF was chosen as the final format due to ease of use and cross-platform support, and the file was embedded into this.

### 5.2.3 Portable Document Format Files

Adobe Pro XI was used to create a set of PDF files where object interactive U3D models were incorporated into each document. In addition to this, photographs of the specimens were also embedded as well as written historical comments (where applicable), an interactive quiz section, discussion section on modern and historical anatomy and a menu with options to access the various features described (Fig. 5.2). Links to further information available online were also included.

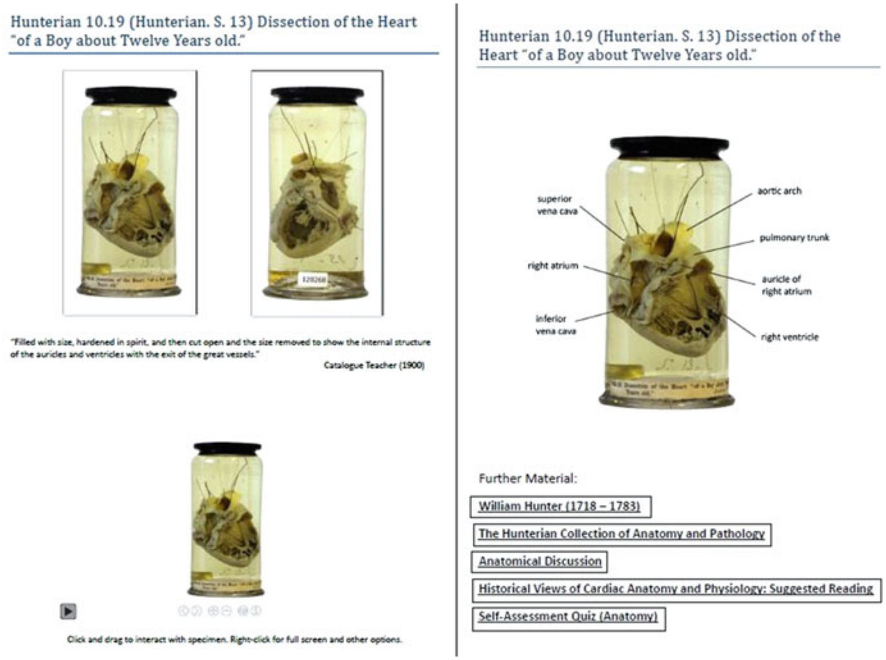


**Fig. 5.2** Two pages from a PDF incorporating an interactive object VR image (*bottom left*) along with selected still images, detail text and labels and links to further sources of information

### *5.2.4 Use of Digitised Specimens in Games and Interactive Applications*

As noted above, the specimens were digitised using two different methods – photogrammetry and object VR. Photogrammetry produces 3D models which can be imported directly into 3D games relatively simply. However, the models produced tend to be very high detail and may result in low performance when imported directly into games developed with, e.g. Unity3D. Further processing (re-topologisation) would typically be required to produce models with simplified 3D geometry and level of detail while preserving a high-quality visual appearance. The models can also be manipulated and used for the generation of 2D images for integration into training packages and games.

Object VR, in contrast, presents a sequence of images that can be manipulated to provide different 2D views of an object. As such, it is not possible to directly integrate these into a 3D virtual environment. This does not mean that they cannot be used in games – but rather than creating 3D objects that can be directly manipulated in game, the presentation of specimens digitised this way would need to be handled differently. For example, when interacting with an object in a 3D environment, a pop-up window could be presented showing the specimen in object VR.

## 5.3 Advanced Digital Imaging of Historical Specimens

In addition to the historical anatomy collections previously mentioned, the University of Glasgow also holds the world's largest collection of pathology collections from Dr. William Hunter's collection. Indeed, as is typical of this type of collection, it is not available to the general public nor is on display for access to the Museum of Anatomy. In a rapidly evolving age of technology with information becoming ever more accessible, museums need to develop novel methods through which to bring their collections out of the museum and within reach of the "digital natives". Though this is currently being explored (Bautista 2014), medical museums rarely place themselves at the forefront of the development of museum exhibitions (Alberti 2011).

Medical museums bridge the fields of medical education and sociocultural history. Through pathological specimens, medical museums can offer an insight into social and cultural history from a perspective unlike that offered by libraries and archives. Collections contained within its walls can span centuries and illustrate an exotic range of pathologies, abnormalities and historical remnants. Yet, perhaps due to the nature of the collections, many medical museums remain under-explored in terms of digital development of museum exhibitions and outreach (Alberti et al. 2008; Mareez et al. 2010).

Moving on from the preliminary work presented earlier, a number of software packages are now available for digitising material (in this case anatomical and pathological collections) from photogrammetry at a more advanced level. We chose a mixture of professional packages, free open-source programmes and free web-based solutions. The packages selected were:

1. Autodesk Memento, 1.0.17.1 and 1.1.0.1
2. Agisoft PhotoScan Standard Edition
3. Autodesk ReCap 360 Trial

Agisoft PhotoScan is seen as the standard software for the creation of photogrammetric models. The two Autodesk packages are aimed at less specialised audiences and were released as beta versions. As such, they lend themselves to easier non-professional use, and, as a result, powerful and graphic-dedicated computers are not required.

### *5.3.1 Agisoft PhotoScan*

Of the three programmes tested, this one is regarded as the most flexible in terms of possible user input. Agisoft PhotoScan also allows for the use of TIFF images and can produce models of much higher resolution. This package also allows for the most freedom of input and manual alteration. The software includes a range of features for modifying and correcting generated 3D meshes – such as filling "holes" to create a fully closed 3D model. Agisoft is available in standard and professional editions. The professional edition includes a number of advanced features not available in standard or in the other packages considered here. Of these, manual camera alignment is most notable. Where the camera is in a known position relative to the object being photographed, this allows the user to set up the alignment explicitly – and can result in improved results in 3D model generation.

### 5.3.2 Autodesk ReCap

This is an entirely web-based service where you can upload photographs from a personal drive. The selected images are then submitted for cloud-based processing. The user then receives an email later with a link when the model has finished.

### 5.3.3 Autodesk Memento

Autodesk Memento appears to be an amalgamation of Autodesk ReCap and Agisoft PhotoScan. It is intended to be a "software suite", and the user downloads this suite and then uploads their relevant images. Similar to Autodesk ReCap, an email is sent to the user when the image has been converted.

### 5.3.4 Selection of Specimens

To ensure that a variety of variables were tested, in relation to the nature of the specimen, a range of historical specimens was selected (Table 5.2). Ten different specimens were identified and used in this study, covering air versus fluid, visibility of the glass and the contents of the jar and physical properties of the specimen. This ensures that a variety of heritage and museum specimen types are considered within these packages used.

### 5.3.5 Imaging

A Canon EOS 600D camera was used with a standard kit EF-S 18–55 mm zoom lens. For consistency and in order to prevent barrel distortion, all images were shot at a focal length of 35 mm, with photographs taken every seven degrees, resulting in 52 images captured per rotation to ensure complete coverage. All images were captured in manual mode. Correct exposure was calculated using a Sekonic L-308S Flashmate light metre in addition to the in-camera light metre. The external metre

**Table 5.2** Selection of historical specimens

| Specimen type | Property |
|---|---|
| Globular aneurism of the root of the aorta, pressing on the pulmonary artery | Wet; medium size; deep orange liquid |
| Central sarcoma of the head of the fibula | Dry; large; very polluted glass; ashy appearance |
| Abscess in bone, osteosclerosis | Dry; medium size |
| Carcinoma of the superior maxilla | Wet; medium size; polluted yellow liquid |
| Lateral curvature of the spine | Dry; very large |
| Erosion of the vertebrae by aneurism | Wet; medium size; yellow liquid |
| Badly united fracture of the femur about the middle | Dry; medium size |
| Tubercular disease of the vertebrae, angular curvature, ankylosis | Dry; large rectangular case |
| Aneurism of the aorta | Liquid |
| Aneurism of the descending aorta | Wet; medium size; clear liquid |

was used as an *incident* light metre, measuring the amount of light falling on the object. The in-camera metre functions as a *reflected* light metre, measuring the amount of light being reflected off the object and into the camera sensor. Aperture was set to f8 or f11 depending on light metre readings and size of the object imaged. A higher f-number provides a smaller aperture and thus a greater depth of field.

The specimens were illuminated with a pair of Bowens StudioLite SL455 lights with tungsten tubes. The lights were installed on stands on either side of the camera to produce relatively even light on the specimen. Barn doors were attached to the lights, allowing for easy adjustment and control of undesired light bounce and reflections.

All images were shot in raw and JPEG. JPEG is a common image format which allows for an adjustable level of compression. Shooting raw allowed for a greater freedom to alter and improve images post-shooting, as opposed to what is possible with JPEG images. Raw files take up more disc space, however, and cannot be used by any of the photogrammetric software tested without first being converted into a compatible format. PhotoScan is able to work with TIFF files. TIFF is the recommended working format within photography, as it does not compress the image files or reduce quality. Raw files were converted into TIFF using Adobe Bridge (CS6 5.0.2.4 x 64).

ReCap and Memento only allow for the use of JPEG files, likely due to the need to upload a collection of image files and hence the need for smaller files. To simplify the number of steps between acquisition and final product, JPEGs were thus produced in-camera.

It also became apparent during the early photogrammetric experimentation that with those specimens in glass cases, trying to reconstruct the casing was problematic, and therefore only the specimen itself was reconstructed.

## 5.3.6 *Image Acquisition Issues*

### 5.3.6.1 Lighting

Lighting was one factor that proved challenging. For larger specimens like the "lateral curvature of the spine", the camera had to be positioned at two levels of height and two sets of images produced to ensure complete coverage. Lighting the specimen from the base resulted in reflections created towards the upper aspect of the specimen. Similarly, lighting from the top part of the specimen resulted in less than satisfactory images towards the base.

### 5.3.6.2 Movement

If a specimen was suspended in the container with, for example, string, imaging had to be done with care, and cessation of movement had to be ensured.

### 5.3.6.3 Coverage

The objects, which were to be imaged, had to be placed centrally on the swivel board used for mounting the specimen on for photogrammetry. For those larger specimens, two sets of images were taken with the centre of the rotation moved to ensure complete photographic coverage.

For those specimens with more complex anatomy, e.g. "aneurism of the aorta", as it had an incisions to highlight the inside wall, this proved problematic when imaging. As the specimen was encased in a glass container, and with this complex anatomy, shadows were cast over regions where the light was shining. This resulted in some areas of deficiency when imaging this specimen as shown in Fig. 5.3.

## 5.3.7 *Results*

### 5.3.7.1 Glass and Encasing

Modelling of the glass containers was not undertaken to ensure it was only the specimen that was focused on. It was initially expected that when taking photographic images, the glass containers would result in complications in the modelling process. This was not always the case, especially related to the dry specimens which tended to produce well-defined models in Memento and ReCap and also in PhotoScan if the time was able to be invested to remove excess voxels. Models obtained when ReCap produced successful results proved challenging to reproduce in PhotoScan. This unexpected result was mainly due to the additional white voxels which tended to appear during processing in PhotoScan, which had to be manually removed.

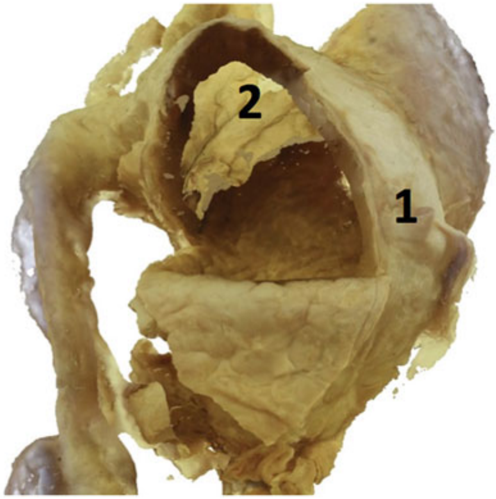


**Fig. 5.3** This image is of the aneurism of the aorta (1) specimen reproduced in PhotoScan. There are areas of deficiency in the model in relation to the internal wall (2)

#### 5.3.7.2 Light

In the "aneurism of the aorta" (Fig. 5.4), specimen was photographed under standard room lights as well as controlled lights to enable a comparison between the two. Agisoft PhotoScan showed little difference in results apart from a severe colour cast. Achieving correct camera alignment proved more challenging when working with the dataset produced under standard ceiling lights, however, and demanded more manual adjustments than what was required for the controlled light dataset. Definite edges did appear somewhat cleaner in the model based on the image sets produced under controlled light.

#### 5.3.7.3 Dry Specimens

The quality of the dry specimen models did not vary significantly amongst those used. The main issue of these specimens was in the fact that they would have a base and top to the container which was sealed and could not be removed from the container due to its historical significance. This resulted in occasional fusing of the container with the specimen when image processing. However, it was noted that this was not as problematic in PhotoScan as the superfluous voxels of the jar could be remodelled prior to mesh production. The digital artefacts produced in ReCap and Memento by the jars could be trimmed relatively easily after model production. This did, however, result in sharp edges and mesh holes. The "lateral curvature of the spine" showed excellent quality in all three software programmes used as shown in Fig. 5.5. Other larger dry specimens produced similar excellent quality of imaging in all three software packages used.

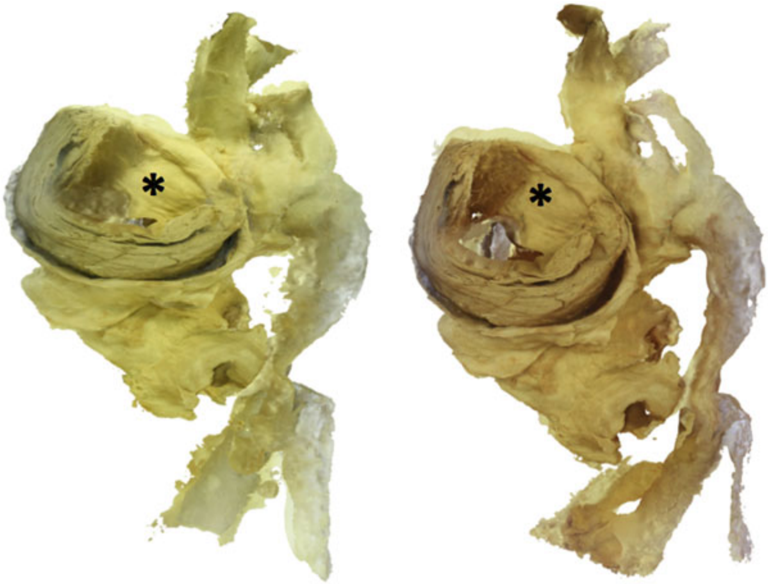

**Fig. 5.4** Aneurism of the aorta specimen where Agisoft PhotoScan was used for the specimen model using regular room lighting (*left*) and controlled light (*right*). The aneurism is highlighted by the *

**Fig. 5.5** "Lateral curvature of the spine" as shown in ReCap

#### 5.3.7.4 Wet Specimens

Wet specimens were a greater challenge in imaging and digital reconstruction. Large differences were observed between results produced in PhotoScan to those produced in the Autodesk programmes. PhotoScan produced some reasonably successful

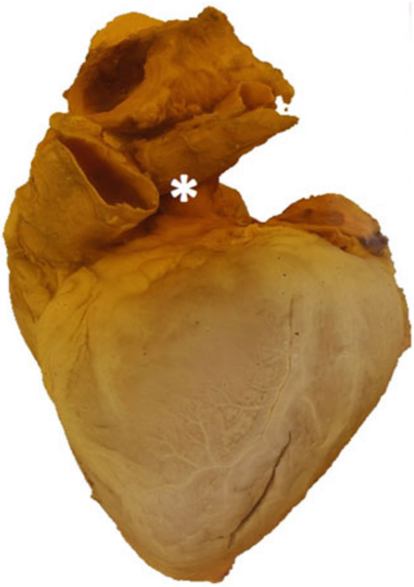


**Fig. 5.6** Image in PhotoScan of the "globular aneurism of the root of the aorta, pressing on the pulmonary artery" specimen

models, whereas ReCap and Memento proved to be consistently unsuccessful. PhotoScan's ability to reproduce wet specimens was found to be unpredictable and sporadic.

The models produced in ReCap proved the least successful, resulting in very poor-quality models barely resembling the original object. Models produced in Memento were occasionally somewhat more successful, in that they resembled the original specimen somewhat. Most of the models appeared fused with its surrounding liquid, however, resulting in a poor representation of the specimen. It was concluded that ReCap and Memento are not appropriate tools with which to reproduce wet specimens.

Interestingly, the specimen "globular aneurism of the root of the aorta, pressing on the pulmonary artery," was immersed in a fluid which had a deep orange tinge to it. However, the resulting model produced in PhotoScan was by far the most successful reproduction of a wet specimen, as seen in Fig. 5.6.

#### 5.3.7.5 Pollution

Working with polluted specimens was a challenge to this study. Agisoft proved beyond doubt, the best of the three programmes, with its high level of user flexibility. ReCap and Memento were not successful in creating digital representation of the e-types of specimens. This allowed for any pollution which was on the glass or in the fluid surrounding the specimen to be easily removed during model creation.

High levels of pollution, however, did obscure parts of the specimens, impeding the overall final quality of the model. This was found to be the case for both dry and wet specimens.

#### 5.3.7.6 Summary

Dry specimens could be reproduced in PhotoScan, Memento and ReCap, and the jars could easily be removed during the processing stage. Wet and/or polluted specimens were more challenging to digitise after photographing. Neither of the Autodesk programmes were able to produce models considered to be successful for the use as a suitable reference image representing the actual quality of the specimen.

Wet specimens which were created in PhotoScan were unpredictable in their reproduction digitally. However, the specimen "globular aneurism of the root of the aorta, pressing on the pulmonary artery", which was significantly discoloured with its surrounding fluid, did in fact result in good reproduction digitally.

It can therefore be seen that depending on the nature of the specimen, it can potentially dictate the best type of software package to use. This therefore has wider implications in the creation of digital museums of a variety of different specimens. It was found that Agisoft PhotoScan was found to be the most versatile package compared to Autodesk ReCap and Memento. However, the user interface and workflow within Agisoft PhotoScan require a deeper understanding of the technical aspects of photogrammetry and digital applications beyond that of the two Autodesk programmes.

However, the two Autodesk programmes were found to be easy to use, and due to the cloud-based processing which Autodesk has, it places no central or graphic processing demands on computer memory capacity. In addition, both Autodesk ReCap and Memento produced successful models of dry specimens with the glass containers only proving to be a minor inconvenience.

## 5.4 General Discussion

### *5.4.1 Medical Museums*

Medical museums help to bridge the gap between medical education and social and cultural history. Anatomical and pathological specimens made available to the wider public help us to gain an insight into the structure and function of the body. In addition to this, they offer a unique perspective which may not typically be revealed by libraries and archives. These types of specimens however tend to remain under-represented in museums, especially from the development of digital museums, exhibitions and material for outreach programmes (Alberti et al. 2008; Mareez et al. 2010).

Historically, medical museums have been slow to adapt to modern tastes, exhibiting material which some can find uncomfortable and with not particularly appealing presentation of materials. However, with the education sector embracing technology and its abilities, additional digital learning tools have increasingly been developed to aid the study of anatomy and physiology (Mareez et al. 2010). Several studies have shown that many students within the medical and related fields find anatomical exhibits and the exposure to the human body as beneficial to their learning and education (Finkelstein and Mathers 1990; Dyer and Thorndike 2000; Dinsmore et al. 2001; Gunderman and Wilson 2005; Alberti et al. 2008; Petridis et al. 2013).

There is a great benefit here of marrying the two together – that of traditional museum exhibits and of digital technology. Technology and its advancements can be mutually beneficial in developing a digital medical museum or exhibit (Martin 2001; Schwarznegger 2012; Boddington et al. 2013; Sampson 2013; Bautista 2014). Here, we have explored the current state of the art in digital capabilities for the development of 3D assets from digitisation of specimens in an anatomical museum using photography-based methods.

## 5.5 Learning and Teaching with 3D

Even before a set of 3D models have been created, it is pertinent and wise to question how they will be used. Changes in technology, and in how students interact with sources of knowledge as a result (Conole et al. 2007), have led to changes in student expectations, attitudes and behaviours. The majority of learners will have access to a range of mobile and home computing devices, which they will use for a mixture of personal and academic purposes. Students may be less likely to turn to books as a primary source, with a preference for digital, online, source materials (Conole et al. 2007).

Such tendencies can, however, be overstated – and it is possible to draw the wrong conclusions from these trends. Kirschner and van Merriënboer (2013) tackle some common perceptions of contemporary students. They note that students are not universally adept with digital technologies as may be inferred from a naïve acceptance of ideas around "digital natives". Similarly, they further note that students are not necessarily competent as self-guided learners, and most will still rely on traditional learning and teaching structures and support.

Indeed, when the Northern Ontario School of Medicine provided undergraduate learners in medicine with laptops and either an iPad or iPhone, wide variation in the use of these devices to support learning was evident (Ellaway et al. 2014). The expectation that all students would enthusiastically adapt to the use of digital devices to effectively support their learning was not observed. These studies point to the issues that can arise when we simply expect students to make effective use of learning technology without support and guidance (Sandars 2012).

However, there are also some positive advantages of multimedia and digital formats when compared to print media. With mobile content delivery, students have access to learning materials anywhere and at any time that suits. Digital formats may also allow students to explore objects in 3D and allow digital manipulation of objects – to allow, for example, viewing from different angles. Students may be able to inspect objects more closely or follow embedded links to quickly access additional information. Self-evaluation tests can also be built in, with instant feedback and/or results stored for tutor evaluation and review of student progress. Learning analytics can also be integrated (Arnold and Pistilli 2012), allowing tutors to monitor student progress – and allowing students a richer picture of their own progression.

While it may be simplistic to assume that these features will automatically make multimedia learning better than traditional media for learning (Mayer 1997), it is clear that well-designed multimedia learning resources have an important role to play in learning and teaching. There are, however, a number of important principles that need to be followed when developing educational multimedia. Mayer (2009) provides a set of detailed principles to follow for effective multimedia instructional design.

Thus, it is not sufficient to digitise a sample of artefacts in a museum and expect these to be of significant educational value without additional effort in developing explanatory materials. To reach their full potential, objects need to be embedded within multimedia or games-based learning environments which provide explanation and room for exploration and for self-evaluation.

### *5.5.1 Embedding in Games*

A notable, but often understated, problem for creating educational games comes not from the challenges faced in instructional design, but is budgetary in nature (Fletcher 2011; Whitton 2012). Commercial games typically have a budget ranging from several hundred thousand pounds to several hundred million pounds per game. As large as the educational game market is, it is not realistic to expect these budgets to be commonly available to developers of new educational content. Even relatively simple mobile games will typically have significant cost when developed to a professional. Outside of large-scale employers in commercial and industrial as well as military enterprises (c.f. Chatham 2011), such budgets are often prohibitive. Several solutions or workarounds are possible.

First, it may be possible to focus development on content for a wide audience, leveraging the economics of scale. For example, a game could be developed for an introductory level undergraduate course taken by students across a range of related disciplines.

Second, it may be possible for tutors to develop games for their own students. While this might seem at the outset a wholly unrealistic expectation – and this will generally be the case – modern game development tools such as Unity3D or

GameMaker have been widely adapted by hobbyists and amateur game developers worldwide. However, these tools are not simple – and require some amount of time to learn. While it is possible to create some good results with just a few months instruction (c.f. Wheatley and Livingstone 2015), we should not expect this option to ever be taken up by a significant proportion of teachers.

A third option is to follow the principles of *constructionism* (Papert and Harel 1991), which promotes the construction of new artefacts as an effective and authentic means to promote learning. Accordingly, an effective approach could be to have students themselves create games. While the games created may be played by peers and colleagues, the goal here is student learning – not the creation of a polished finished product. Accordingly, the tools used and polish required do not need to match those expected in either of the previous options considered. As a result, it becomes possible for a wider range of students to engage, with support from tutors, in the creation of learning games. Tools such as Scratch have been developed which enable young children (in K12 or primary school) to create games (Resnick et al. 2009; Wilson et al. 2013), while Unity plugins such as *PlayMaker* or *Blueprints* in the unreal game engine allow the creation of interactive 3D simulations and games without requiring any programming.

## 5.6 Conclusions

A key challenge in the development of interactive museums, whether online, mobile, immersive or game based, is the digitisation of the collection and development of related 3D assets themselves. Anatomical collections commonly have additional challenges – given complex shapes and forms and the storage of specimens in glass containers with or without liquid. Despite this, current tools and production pipelines are able to create high-quality visualisations – in worst-case scenarios with 2D image-based representations (object VR), but more typically with the generation of high-quality, highly accurate 3D models (photogrammetry).

Best-quality results rely on using more complex software solutions and are a more involved process, but it is now possible for almost anyone with relatively little technical training to begin the time-intensive process of digitisation. Anatomical museums have long been useful repositories of unique artefacts to support learning and public engagement, but these have been relatively inaccessibly and their potential largely untapped. Through digitisation and the inclusion of the resultant digital models into online museums, interactive displays and games, we now have the potential to open up these (effectively) hidden archives to wider audiences and to make anatomically accurate models more widely available as reusable assets for integration in learning through games.

Requiring only a camera and free or low-cost software, photogrammetry is a viable option for the creation of 3D assets for use in multimedia learning and games. While achieving best results for challenging samples takes some expertise and experience, usable results are within reach of novices with minimal training.

Developing games utilising these is a greater challenge, but having high-quality art assets readily available enables professionals, tutors and even students themselves to develop serious games with anatomically accurate 3D models – without any need to master 3D modelling itself.

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# Chapter 6
# Towards the Development of a Virtual Reality Simulator with Haptic Force Feedback for Training in Stereotactic Brain Biopsies

**Laura Pérez-Pachón, Matthieu Poyade, Jennifer Brown, and Val Fallon**

**Abstract** Neurosurgery training traditionally follows the *apprenticeship model* of learning using supervised 'hands-on' skill acquisition in the operating theatre. With technological advancements in computer-generated images and interactive technologies, haptic-based virtual reality simulators have been shown to provide successful workbenches for realistic training in surgical procedures. The use of haptic force feedback in virtual reality simulates the tactile properties of tissues and surgical instrumentation manipulation, which increases the degree of realism for the 'operating surgeon' and enables the acquisition of surgical skills in a safe virtual learning environment. A pilot study was conducted whereby anatomical structures were modelled from medical datasets using segmentation algorithms and modelling platforms and applied as three-dimensional content to a haptic-based virtual learning environment of a stereotactic brain biopsy procedure. This has seen the creation of a prototype haptic-based virtual reality simulator which, with further development, may complement traditional neurosurgery training in stereotactic brain biopsies.

**Keywords** Haptics • Surgical simulation • Neurosurgery • Stereotactic biopsy • Force feedback • Surgical training • Virtual reality

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## 6.1 Introduction

This chapter presents a methodology for the creation of a haptic-based virtual reality simulator which, with further development, aims to complement traditional neurosurgical training in stereotactic brain biopsies by enhancing the surgical skills through simulation of surgical procedures without the need of a patient or close consultant supervision.

The study framework is firstly presented with descriptions of the surgical procedure and the traditional 'apprenticeship model' of surgical training. Following this, motor skill training using haptic technologies is discussed, with reference to the importance of pursuing an appropriate degree of realism in surgical simulations. The materials, methodological and technological framework are described, including the design and implementation of a complex haptic-based virtual reality simulator using a conventional game engine. Finally, the results from a heuristic evaluation and feasibility study of this tool are presented and discussed.

### *6.1.1 Stereotactic Brain Biopsies and Traditional Surgical Training*

In neurosurgery, tissue samples are obtained from targeted structures and analysed under a microscope in order to diagnose certain pathologies. A stereotactic brain biopsy is a minimally invasive surgical procedure which allows the neurosurgeon to extract a sample of a brain lesion for examination (Burger and Nelson 1997). In frame-based stereotactic brain biopsies, a frame is attached to the patient's head for triangulation of the abnormal area. This external reference system serves as a guide for the needle insertion across the minimal iatrogenic brain trauma trajectory (Bhade et al. 2002).

Guided radiological imaging plays an important role in identifying the best trajectory for the biopsy needle insertion (Rosseau et al. 2013). Magnetic resonance imaging (MRI), computed tomography (CT) scans and three-dimensional (3D) computer imaging techniques are used in this procedure to calculate the exact coordinates of the target tissue. This helps minimizing permanent damage to critical structures, especially where abnormal anatomy is located in deep parts of the brain. In addition, identifying the best needle trajectory is important for obtaining valid results that will allow planning a treatment strategy. However, the surgeon only knows if the tumour has been appropriately sampled following microscopic examination of the extracted tissue. Occasionally, tissue sampling is not sufficient to achieve a satisfactory diagnosis, and the procedure must be repeated, thus increasing the risk of surgical complications and patient recovery time. Sampling the most viable region, especially for deep-seated tumours with tissue heterogeneity, is complicated and requires high level of expertise and dexterity (Iijima et al. 2015).

Given the delicate nature of this procedure, transferring the motor skills required for the performance of stereotactic brain biopsies is a difficult task. In this sense, guiding a biopsy needle towards the brain structures involves the sense of touch, making practical experience indispensable for the learning process. For this reason, residents train upon patients following the apprenticeship model where clinical and technical skills of invasive procedures are learned through practice under the guidance of an experienced mentor. Unfortunately, the apprenticeship model as applied to surgical training has some drawbacks including concern for patient safety, trainee learning limited by both the working time directive and infrequency of surgical opportunities and difficulty in quantitatively assessing trainee performance (Fried et al. 2005; Aggarwal et al. 2006; Delorme et al. 2012; Rosseau et al. 2013).

The aforementioned reasons clearly indicate that an effort must be done to keep the theatre environment as risk-free as possible and adjust current training methods to meet the advances in surgical techniques. The World Health Organization (WHO) indicated in 2009 that expecting safe management from untrained personnel with inadequate resources is an unsafe practice (WHO 2009). Furthermore, it advised the medical field to adopt the practices of the aeronautical and nuclear industries, where training is carried out in a controlled environment using technological innovations such as simulators. This type of simulated training would not only benefit trainees but serve as an ongoing training tool, outside of the operating theatre, for surgeons in residence.

### 6.1.2 Motor Skill Training and Haptic Technologies

Motor skill training is an internal process of improvements in the capability to perform an action through practice (Schmidt and Wrisber 2008) and is strongly associated with the sense of touch, which is the result of both tactile and kinaesthetic feedback; tactility is detected by skin receptors and allows humans to feel smooth/rough and hot/cold surfaces, as well as pain, while kinaesthesia is detected by muscular and joint receptors which provide proprioception. The use of the sense of touch to interact within a virtual environment that provides information to the user is called haptic feedback.

With the rise of computer-generated images and interaction technologies during the past decades, haptic-based virtual reality simulators have shown to provide successful workbenches for realistically training complex surgical procedures (Fried et al. 2005; Larsen et al. 2009; Delorme et al. 2012; Schirmer et al. 2013), such as minimally invasive surgery where sense of touch is deprived in comparison with open surgery (Moody et al. 2002). Haptic-based virtual reality simulators assist motor skill training on surgical tasks through the repetition of complex procedures and assessment of technical skills requiring tactile, kinaesthetic and visual cues. Their use has fostered the development of new training systems which are capable of simulating tissue tactile properties and surgical instrument manipulation, providing awareness of the amount of force that needs to be applied to delicate tissues and suture materials. These systems enable surgeons to practise in a realistic virtual environment which provides augmented feedback on motor skill performance to enhance proficiency in advance of entering the theatre (Bajka et al. 2009; Timothy et al. 2011).

The majority of the investigations support the implementation of haptic feedback onto virtual reality simulators, but some authors underline that practising on a haptic system with a low degree of realism could lead to tissue damage in a clinical setting, for example, when pulling and pushing forces are involved (Chamarra et al. 2008). Despite the controversy, there is a general agreement that validation and financial implications must be considered before implementing haptic-based virtual reality simulators into surgical training curricula. As indicated by van der Meijden and Schijven (2009), some factors must be assessed, such as the degree of improvement of motor skill training for the performance of the simulated task, the existing alternatives such as surgical box trainers or the evaluation of key features such as the optimal force which must be generated through haptic feedback or the areas where haptic feedback can be applied.

### *6.1.3 How Haptic Technologies Assist Surgical Training*

Haptic-based virtual reality simulators have the potential to reduce patients' risk and the incidence of preventable errors, solve problems related to hospitals' protocols through the integration of alternative training methods outside the operating theatre, accelerate the learning curve in motor skill acquisition and facilitate the assessment of performance.

The most important advantage of haptic-based virtual reality simulators is that these systems reduce the number of surgical errors and provide better quality of healthcare during residency training (Cohen et al. 2013), as they allow the transfer of skills from a preoperative environment to the theatre in relaxed training facilities and enable detection, analysis and identification of surgical errors and near misses (Fried et al. 2005). In addition, haptic-based virtual reality simulators help reduce extended operating times caused by surgical training through the provision of inexpensive facilities for training in a preoperative environment (Larsen et al. 2009). Investment in haptic-based virtual reality simulators by hospitals is supported by several authors who consider that the financial impact of conventional training through the apprenticeship model justifies the investment in virtual surgery for trainee education (Farnworth et al. 2001). In their study, Delorme et al. (2012) indicated that the payback period for hospitals purchasing simulators is 6 months due to the savings in training costs and higher operating theatre efficiency.

Besides healthcare and financial implications, several validation studies have shown that haptic-based virtual reality simulators accelerate the learning curve compared to the apprenticeship model. Larsen et al. (2009) explained that the learning curve is initially associated with an increase in the complication rate and found that 8 h of intensive training using their simulator was equivalent to 28 salpingectomies which may take a year in clinical practice. Delorme et al. (2012) found that trainees completed laparoscopic cholecystectomy interventions 29% faster and were five times less likely to injure the patient. In these cases, simulator training reduced operating time and increased surgical proficiency. Other validation studies have proved the benefits of using haptic-based virtual reality simulators in the initial stages of surgical training. For instance, the first commercially available laparoscopic salpingectomy simulator (LapSim® Laparoscopic Trainer; Surgical Science, Gothenburg, Sweden) benefits inexperienced subjects more likely than intermediate and experienced surgeons, who show a non-significant difference in their performance as they are already reaching the plateau of their learning curve (Aggarwal et al. 2009). The acceleration of the learning process and impact in trainee performance by using an appropriate haptic-based virtual reality simulator is a clear advantage compared to the outcomes of the traditional apprenticeship model, especially in the initial stages of surgical training. Finally, objective skill assessment can be done through quantitative methods and may be performed periodically, facilitating the detection and analysis of potential errors and therefore making surgical training more effective.

## 6.2 Aim

The aim of this study is to create a prototype of a haptic-based virtual reality simulator to support motor skill training in the insertion of a biopsy needle and sample collection during a stereotactic brain biopsy. Also, the study aims to perform a parameterization of this training tool and a face validity study to analyse its accuracy and impact on surgical training.

This research is in line with previous studies which have investigated the utility of haptic-based virtual reality simulators to provide motor skill training to gain experience with no risk to patients (Fried et al. 2005; Schirmer et al. 2013; Larsen et al. 2009; Delorme et al. 2012). To the best of the authors' knowledge, a prototype of a haptic-based virtual reality simulator for the biopsy needle insertion and sample collection during a stereotactic brain biopsy has not been developed thus far.

## 6.3 Apparatus and Methods

### *6.3.1 Materials*

#### 6.3.1.1 Dataset

Consent for use of patient data was obtained from Greater Glasgow and Clyde National Health Service ethics committee in respect of a patient with a suspected deep-seated suprasellar brain tumour. Three different digital imaging and communications in medicine (DICOM) datasets were selected for the segmentation and surface generation process: MRI with gadolinium contrast, MRI without contrast and a CT scan.

#### 6.3.1.2 Data Extraction and Visualization

The MRI with contrast was used for the tumour segmentation as these data show abnormal tissues and disease processes as regions of higher light intensity. T2-weighted images from the MRI scans without contrast were used to visualize the cerebral spinal fluid (CSF) spaces, while T1-weighted images were used for the segmentation of the soft tissues. Finally, the CT scan data were used for the segmentation of the skull. The segmentation and surface generation of the anatomical structures were developed using Amira 5.6 (FEI 2016). These anatomical models were texturized and enhanced with Autodesk 3DS MAX 2015 and Mudbox (Autodesk 2016). Unity 4.6 (Unity 2015) and C# were used to create the virtual environment. Finally, the design of the interface was developed using Adobe Illustrator and Photoshop CS6.

#### 6.3.1.3 Haptic Interface

The haptic interaction was provided by Geomagic (Geomagic 2015). A plug-in package provided by the Glasgow School of Art (Digital Design Studio) was used for the implementation of the haptic interaction in Unity (Poyade et al. 2014). This plug-in was developed in C++ using the application programming interface OpenHaptics® from Geomagic and enables implementing advanced haptic interaction using C# scripting (Unity 2015). The Geomagic Touch/Phantom Omni was used as the haptic interface. This device is a punctual inter-actuator capable to sense position and orientation on 6DOF input and render forces up to 3.3 N onto 3DOF output within a delimited workspace, up to 160 W × 120 H × 70 D mm (Poyade et al. 2009).

### *6.3.2 Methodological and Technological Framework*

A workflow pipeline (Diagram 6.1) was designed for extracting and modelling relevant anatomical structures from medical datasets using anatomical segmentation algorithms and modelling platforms and reusing them as 3D content in a haptic-based virtual environment supported by Unity 4.6.

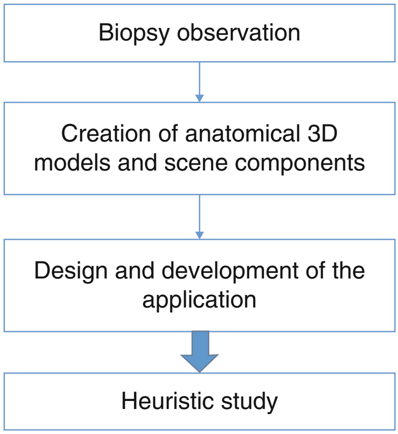



**Diagram 6.1** Workflow pipeline

#### 6.3.2.1 Biopsy Observation

The first phase of this research involved observing a stereotactic brain biopsy procedure in order to determine the procedural steps to be represented in the design of the haptic-based virtual reality simulator. Collaboration with the medical staff was essential to define the functionalities of the simulated procedure and to obtain information for the modelling of surgical instrumentation to be used in the virtual environment.

In a frame-based stereotactic brain biopsy, samples for collection are targeted via an image-guided needle trajectory on an external frame attached to the patient's head. The biopsy needle is composed of inner and outer cannulas, both with a side-cutting port near the tip where a little portion of tissue is collected. The tip of the needle is blunt to reduce the risk of injury during passage of the needle through the brain. In the first place, the two cannulas are assembled and inserted together into a guide holder on the stereotactic frame and gradually advanced to the previously defined depth, paying attention to tissue density changes which may indicate that the tumour has been pierced. Then, the hub of the inner cannula is rotated so that the side ports on the two cannulas coincide, opening the side-cutting port. The side-cutting port must be closed before the insertion in order to avoid unnecessary tissue damage. For the sample collection, the inner cannula is opened and a slight negative pressure is applied using a syringe. Then, the inner cannula is closed and withdrawn. Several samples may be obtained by rotating the outer cannula in order to collect tissue from the anterior, posterior, medial and lateral sides of the target point or by slightly varying the depth of the needle. The steps involved in the biopsy needle insertion and sample collection are represented in Diagram 6.2.

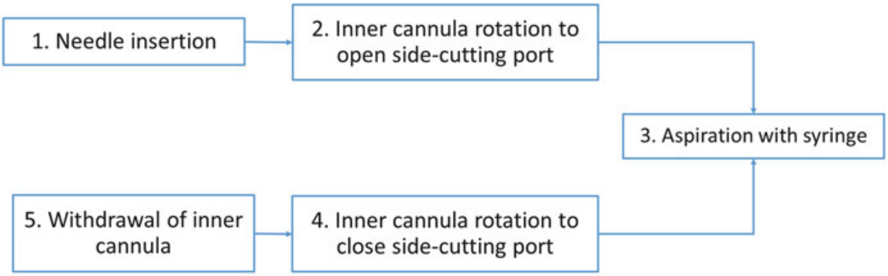



**Diagram 6.2** Steps involved in the biopsy needle insertion and sample collection

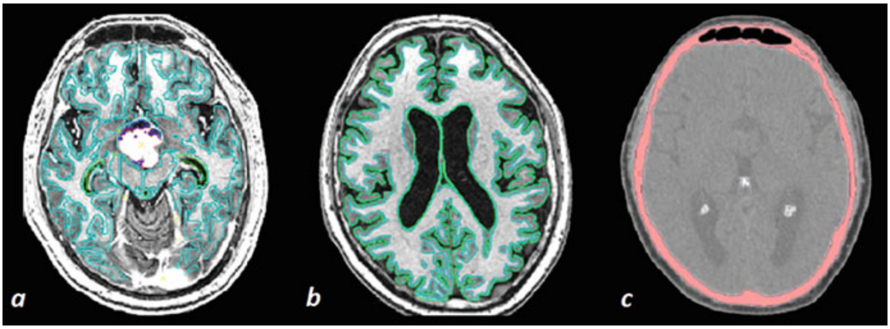



**Fig. 6.1** (**a**) Tumour segmentation (MRI with contrast), (**b**) cortex and white matter segmentation (MRI without contrast), (**c**) skull segmentation (CT scan)

#### 6.3.2.2 Creation of Anatomical 3D Models and Scene Components

The clinical datasets were imported into Amira 5.6 and analysed in order to select the most suitable option for the segmentation and surface generation of the anatomical structures. Automatic segmentation was initially carried out, selecting a range of light intensity values throughout the whole dataset (Fig. 6.1). Following which, manual segmentation was performed, slice by slice, in order to redefine primary borders where light intensity between different anatomical structures was homogeneous. After segmentation, anatomically accurate 3D models of the tumour, cyst, cortex and white matter were obtained.

After the segmentation and surface generation, object files of the anatomical 3D models were obtained. At this point it should be noted that the surface generation algorithm interpolates the segmented data across the layers of the whole dataset and interprets the information on the space between slices. During this process, holes and artefacts may be created especially in complex structures. Indeed, this was the case for the structure showing the highest complexity, the cortex. The cortex covers the white matter and adopts intricate shapes across the gyri and sulci of the brain. For this reason, numerous holes appeared mostly in the occipital lobe, and removal of artefacts was done using Autodesk 3DS MAX and Mudbox. Then, textures were applied to the anatomical models for enhancement (Fig. 6.2).

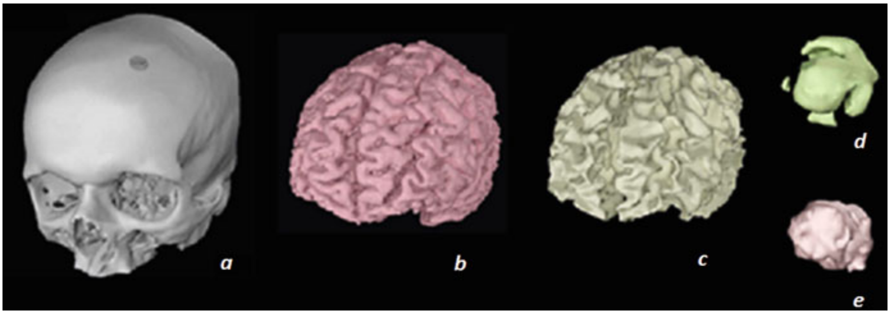



**Fig. 6.2** Renders of 3D anatomical models: (**a**) skull, (**b**) cortex, (**c**) white matter, (**d**) cyst and (**e**) tumour

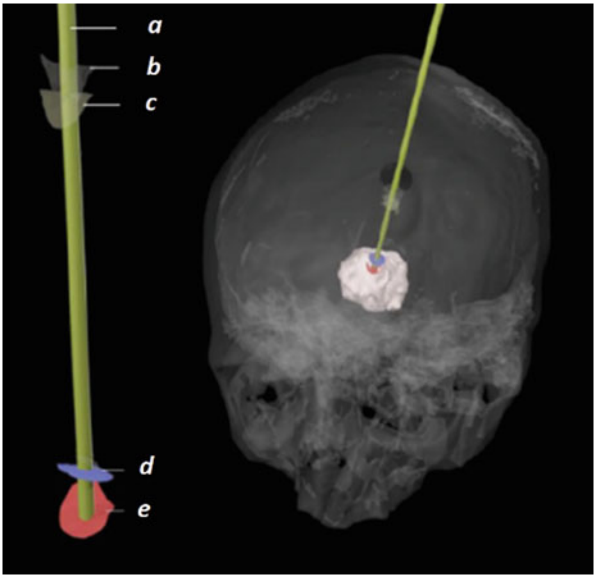



**Fig. 6.3** Render showing the haptic object model: (**a**) cylinder, (**b**) cortex, (**c**) white matter, (**d**) cyst and (**e**) tumour

After post-processing the anatomical models, a biopsy needle trajectory was defined. An area of the cortex anterior to the motor strip and a region of the tumour surrounded by cystic tissue were selected as the entry and target points, respectively. As the graphical representation of anatomical models is computationally expensive due to their size, a haptic object was created to allow the correct puncture interaction with the haptic cursor during the simulation. That haptic object is not visible to the user in the virtual environment. The haptic object consisted of a cylinder, aligned with the entry and target points, which pierces the boundary of the anatomical models along its trajectory. Figure 6.3 shows the cylinder and layers of the cortex, white matter, cyst and tumour forming the haptic object.

**Fig. 6.4** Render showing a 3D model of the biopsy needle (inner cannula inserted into the outer cannula)

**Fig. 6.5** Side-cutting port

**Fig. 6.6** 'Luer' lock attachment

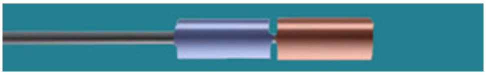
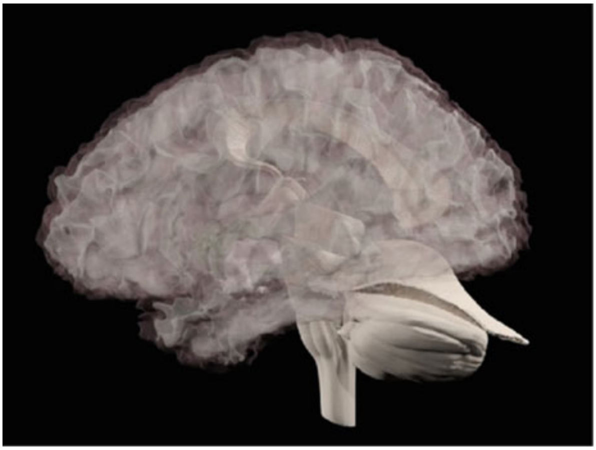


**Fig. 6.7** Render showing the 3D models from body parts combined with Amira models



The stereotactic frame and biopsy needle were modelled with Autodesk 3DS MAX, using the Leksell® Stereotactic System (Leksell 2015) as reference. The biopsy needle (Fig. 6.4) was modelled representing the inner and outer cannulas with a side-cutting port at the tip (Fig. 6.5) and a 'Luer' lock attachment (Fig. 6.6) for the syringe. The inner and outer cannulas were assigned different colours: red and blue, respectively. The anatomical models created from the clinical images were combined with models of the cerebellum, corpus callosum, pons, midbrain and medulla oblongata (BodyParts3D 2015) to enhance the visualization (Fig. 6.7). The 3D model of the stereotactic frame was then combined with the anatomical models, aligning its components according to the biopsy needle trajectory previously defined (Fig. 6.8). The coordinate scales were set onto the virtual frame to provide an accurate representation. The first component to be aligned was the guide holder. Following which, the remaining components (arc, arc supports, rings, base and posts) were placed accordingly. Additionally, models of the skin (TurboSquid 2014), a stretcher and cloth were incorporated to add realism to the simulator (Fig. 6.9).

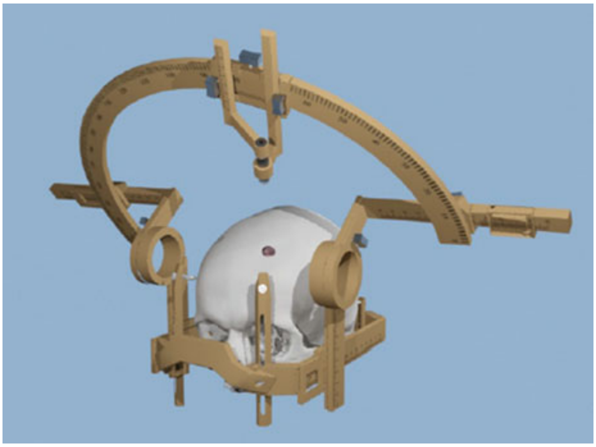


**Fig. 6.8** Combination of the stereotactic frame and anatomical models

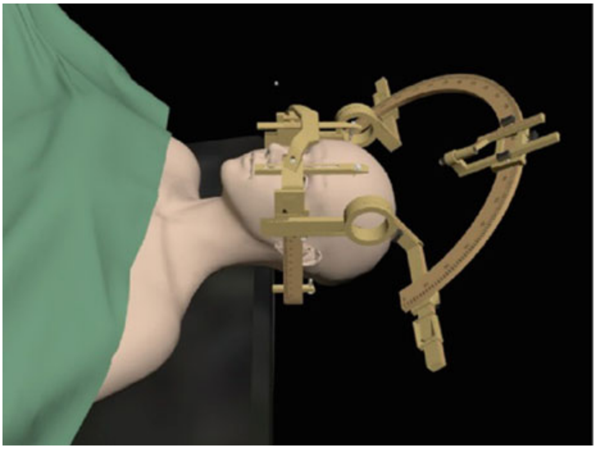


**Fig. 6.9** Render showing the 3D model of the stereotactic frame attached to the patient, along with the skin and stretcher

#### 6.3.2.3 Design and Development of the Application

Unity 4.6 and C# programming language were used to develop a stand-alone application with a $1024 \times 768$ resolution. The application is composed of different scenes providing general information about stereotactic brain biopsies and the role of haptic-based virtual reality simulators (Fig. 6.10), as well as a set of instructions about the functioning of the simulator.

The simulator scene includes a main viewport showing a virtual patient with the stereotactic frame attached to the head, plus two secondary viewports that provide real-time assistance to the user throughout the performance of the biopsy needle insertion and the sample collection (Fig. 6.11). The viewport on the left top corner of the screen aims to help the user to appreciate the depth at which the biopsy needle is inserted and its distance from the tumour. The viewport on the right top corner

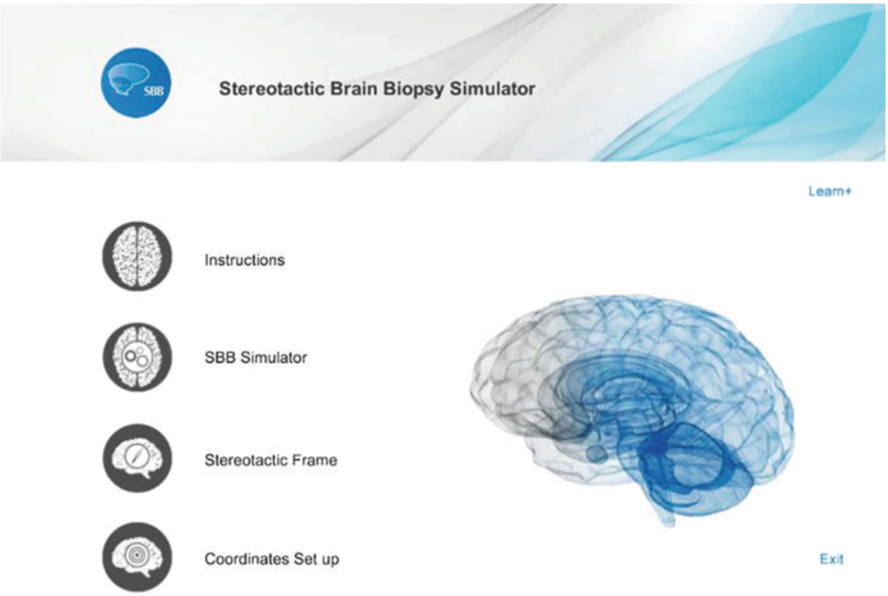



Fig. 6.10 Main menu

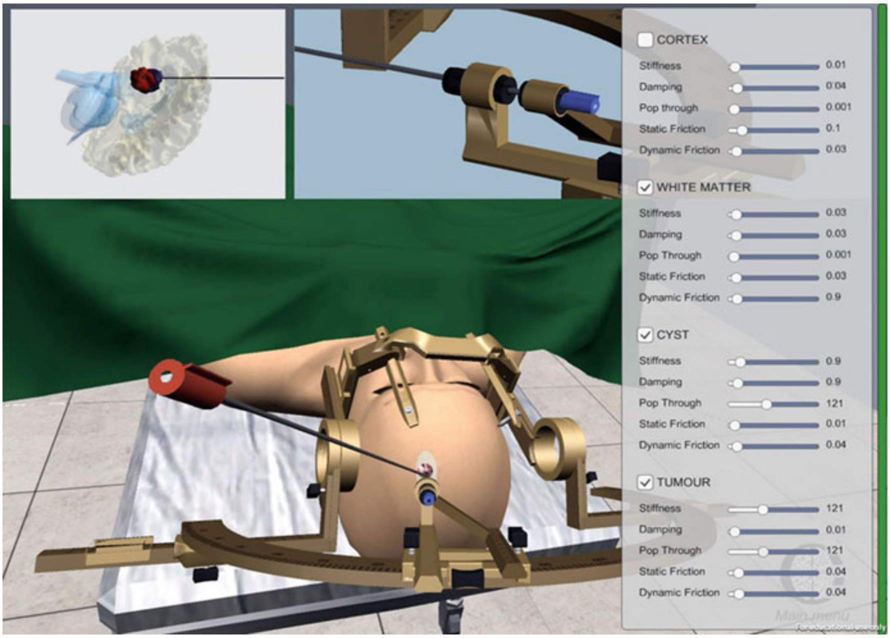



Fig. 6.11 Stereotactic brain biopsy simulator

**Table 6.1** Haptic properties corresponding to the characteristics of the virtual tissues

| | | |
|---|---|---|
| Stiffness | Controls how hard surfaces feel | 0 = compliant surface |
| | | 1 = hardest surface |
| Damping | Controls the springiness of the surface | 0 = no damping |
| | | 1 = maximum level of damping |
| Pop through | Controls the amount of force to go through the geometry surface | 0 = disables the pop through |
| | | 1 = maximum force that is required to go through |
| Puncture static friction | Controls how hard it is to move inside a punctured shape starting from a static position | 0 = frictionless tissue |
| | | 1 = maximum amount of friction |
| Puncture dynamic friction | Controls how hard it is to move inside a punctured shape when motion has already been engaged | 0 = frictionless tissue |
| | | 1 = maximum amount of friction |

Values relative to the definition of forces in OpenHaptics® application programming interface

of the screen shows a close-up view of the guide holder on the stereotactic frame in order to help the user with the insertion of the biopsy needle. The simulator includes a control panel with sliders to adjust each haptic property value and toggles to isolate the anatomical structures in the top left viewport. This panel was used for the determination of the haptic characteristics of the tissue in a heuristic study (Fig. 6.11).

The haptic interaction was implemented in the simulator scene (Fig. 6.11). The plug-in package for haptics in Unity (Poyade et al. 2014) provided a set of scripts to define the haptic functionalities required to simulate an injection-like procedure. The script which allows specifying the haptic properties of the anatomical structures (Table 6.1) was assigned to the haptic object, and the puncture mode which comprises advanced properties to support the haptic puncture effect was selected. The *stiffness*, *damping* and *pop through* define the characteristics of the boundary of the anatomical structures, while density is defined by the *punctured static friction* and *punctured dynamic friction*. Additionally, this script was assigned to the frame components and the skin model, setting the pop-through value to 0 so that they cannot be punctured.

The virtual biopsy needle was set as the haptic cursor, which is controlled by the user through the haptic device and its movement can be seen in real-time during the simulation. As in real life, the maximum penetration of the biopsy needle was set to a certain value (83% in this case) so that the needle reached the target tissue. Also, a haptic camera was created and assigned a haptic workspace. A function was created in order to calculate the vector of the biopsy needle trajectory. Finally, a function to adjust and render the haptic properties of each structure using the sliders in the control panel was implemented.

Figures 6.12, 6.13 and 6.14 show a scene where the different anatomical models may be isolated or their transparency changed to observe the inner structures which can be compared to the clinical images. Figure 6.15 shows a scene with a 3D model of the stereotactic frame, and Fig. 6.16 shows a scene which provides information about how to attach the stereotactic frame to the patient's head.

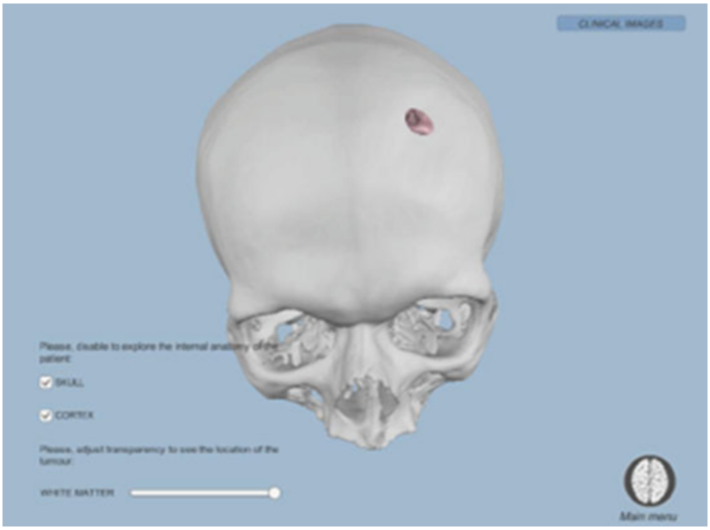


Fig. 6.12 Visualization of the skull

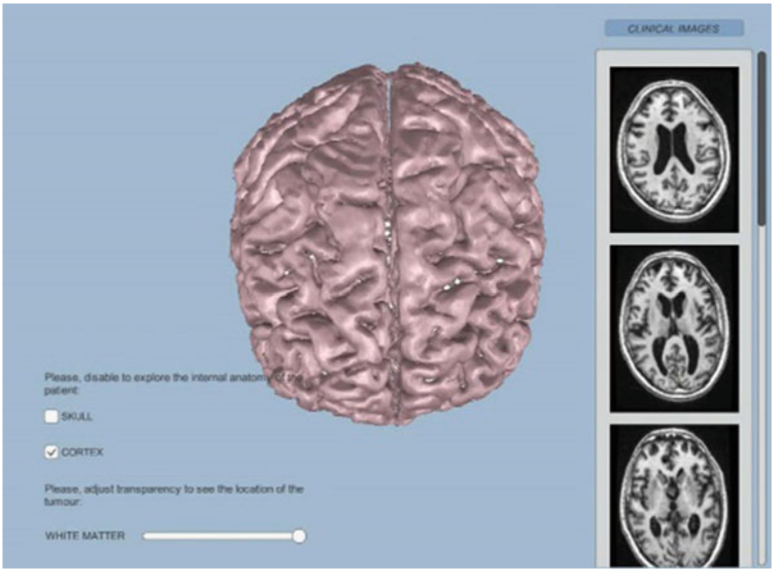



Fig. 6.13 Visualization of the cortex and clinical images

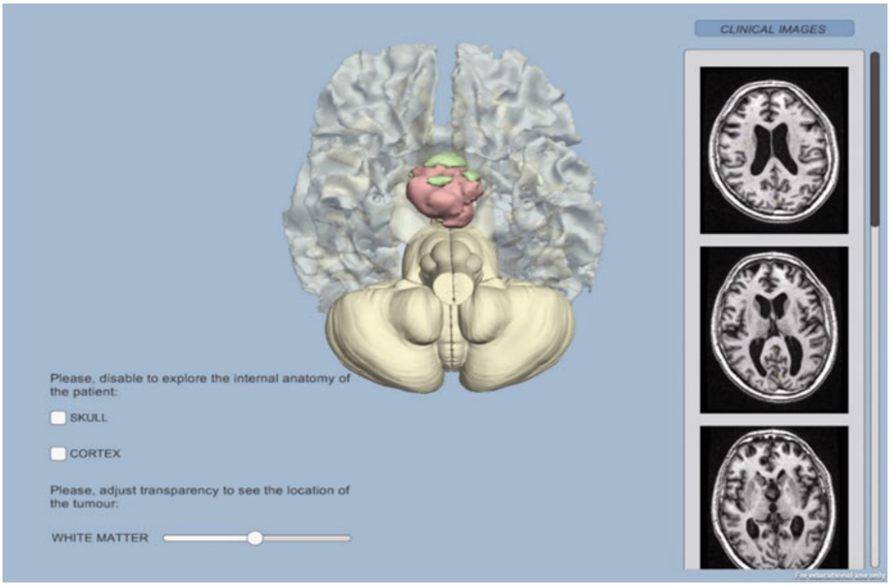



**Fig. 6.14** Visualization of the white matter and abnormal tissue

**Fig. 6.15** Scene 'stereotactic frame'


## 6.4 Heuristic Study

An expert neurosurgeon from the Queen Elizabeth University Hospital Glasgow conducted a heuristic study of the simulator prototype. A desktop computer was used to render the haptic geometries and virtual environment. The expert was positioned in front of a monitor with the haptic device aligned in her line of sight and was asked to interact with the virtual environment using the virtual biopsy needle

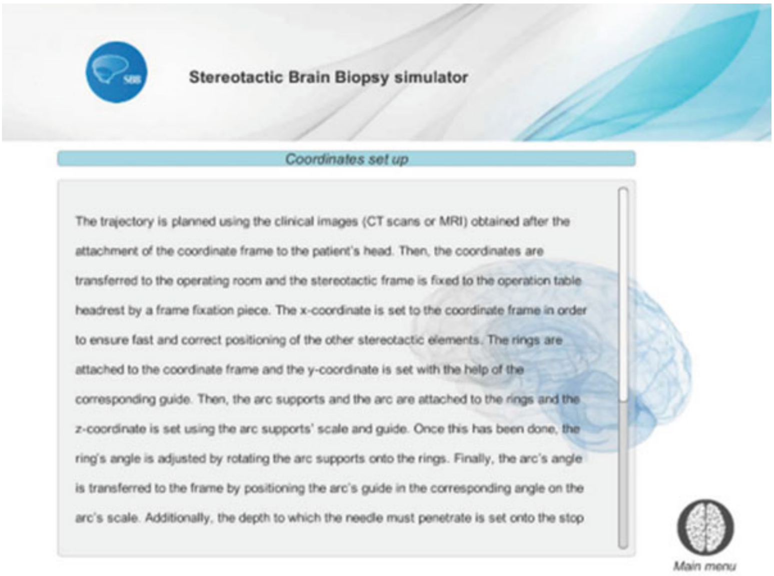



**Fig. 6.16** Scene 'coordinates set-up'

simulated by the haptic device. A questionnaire based on a typical five-level Likert scale was used to rate the prototype. The functioning of the simulator was explained to the expert who was then asked to follow a set of instructions.

The first step was the parameterization and analysis of the haptic force feedback. In this part, the questionnaire asks the expert to follow the simulated procedure. There is also information on how to adjust the haptic properties in the control panel and isolate the anatomical models shown in the viewport in the top left corner of Fig. 6.11. The second part contains questions about the anatomical accuracy of the models in terms of their shape, texture and location. The third part analyses the instrumentation, including questions about the realism of the stereotactic frame and biopsy needle, and how the latest is mapped in the virtual environment. Finally, the fourth part is dedicated to the expert's evaluation of the future potential of the simulator.

## 6.5 Results

A simulation has been developed and incorporated into an interactive application that contains information about the functioning of the haptic-based virtual reality simulator and surgical procedure and allows the interaction between the user and the 3D models.

### 6.5.1 Parameterization and Analysis of the Haptic Force Feedback

During the parameterization, the haptic force feedback was refined by the expert, specifying the amount of force which must be generated during the insertion of the biopsy needle. Table 6.2 presents the results of this process for each anatomical structure. Subsequently, the expert analysed these results and classified them according to the realism of the haptic interaction (Table 6.3).

### 6.5.2 Assessment of the Anatomical Accuracy

Table 6.4 presents the results of the analysis of the anatomical models' accuracy in terms of shape, texture and location of the abnormal tissue.

### 6.5.3 Assessment of the Instrumentation

Tables 6.5 and 6.6 show the results from the analysis of the accuracy of the stereotactic frame and biopsy needle. Table 6.7 shows the results from the analysis of the mapping, biopsy needle's functionality and procedural steps.

**Table 6.2** Results of the parameterization

| Structure | Stiffness | Damping | Pop through | Punctured static friction | Punctured dynamic friction |
|---|---|---|---|---|---|
| Cortex | 0.01 | 0.04 | 0.05 | 0.01 | 0 |
| White matter | 0.03 | 0.03 | 0.01 | 0.03 | 0.35 |
| Cyst | 0.01 | 0 | 0.09 | 0.01 | 0.01 |
| Tumour | 0.03 | 0 | 0.09 | 0.05 | 0.04 |

Values relative to the definition of forces in OpenHaptics® application programming interface

**Table 6.3** Results of the analysis of the haptic force feedback

| Structure | Accuracy |
|---|---|
| Cortex | 4 |
| White matter | 4 |
| Cyst | 4 |
| Tumour | 4 |
| Insertion/extraction of inner cannula | 1 |

*1* Strongly disagree, *2* disagree, *3* neutral, *4* agree and *5* strongly agree

**Table 6.4** Results of the anatomical accuracy analysis

| Structure | Shape | Texture | Location of the abnormal tissue |
|---|---|---|---|
| Skull | 5 | 4 | – |
| Cortex | 4 | 3 | – |
| White matter | 5 | 5 | – |
| Cyst | 5 | 3 | 5 |
| Tumour | 5 | 4 | 5 |

*1* Strongly disagree, *2* disagree, *3* neutral, *4* agree and *5* strongly agree

**Table 6.5** Results of the analysis of the stereotactic frame in terms of its realism

| Stereotactic frame | Accuracy |
|---|---|
| Base | 5 |
| Rings | 5 |
| Arc supports | 5 |
| Arc | 5 |
| Guide holder | 5 |

*1* Strongly disagree, *2* disagree, *3* neutral, *4* agree and *5* strongly agree

**Table 6.6** Results of the analysis of the biopsy needle in terms of its realism

| Biopsy needle | Accuracy |
|---|---|
| Side-cutting port | 5 |
| Hub | 5 |
| Texture | 5 |

*1* Strongly disagree, *2* disagree, *3* neutral, *4* agree and *5* strongly agree

**Table 6.7** Results of the analysis of the instrumentation

| Feature | Accuracy |
|---|---|
| Mapping | 4 |
| Biopsy needle's functionality | 3 |
| Procedural steps | 3 |

*1* Strongly disagree, *2* disagree, *3* neutral, *4* agree and *5* strongly agree

## 6.6 Discussion

Unity 3D has shown to be a useful platform for the development of a haptic-based virtual reality simulating tool, as it offers the possibility of presenting diverse image data combined with high-resolution 3D rendering and real-time interaction. The user may explore the 3D objects with great freedom and obtain information about individual structures along with their surface texture characteristics, which are missing from planar images.

Pursuing a high degree of realism plays a key role in the suitability of haptic-based virtual reality simulators where accurate tactile, force and visual feedback are necessary (van der Meijden and Schijven 2009). With this in mind, a parameterization and analysis of the accuracy of this prototype have been carried out with a view to shaping its future development.

### *6.6.1 Parameterization and Analysis of the Haptic Force Feedback*

Bidirectional input and output have been addressed in the literature as important features for building realistic haptic-based virtual reality simulators (van der Meijden and Schijven 2009). This prototype allows representation of the tactile properties of anatomical tissues. In addition, these haptic properties may be modified by the user, not only allowing parameterization but also providing the possibility to practise on different case scenarios by modifying the abnormal tissue properties.

When performing a stereotactic brain biopsy in real life, the cortex shows some resistance to piercing. For this reason, the *pop-through* value of the cortex was set to 0.05 so that some resistance could be detected (Table 6.2). On the contrary, the white matter does not show any resistance in real life; thus, the *pop-through* value for the white matter was set to 0.01. In spite of these adjustments, the expert still detected a considerable amount of resistance from the white matter's boundary after the parameterization, which is due to the fact that the stiffness and damping values affect the hardness and springiness of the boundary. Therefore, this problem may be solved by adjusting the stiffness and damping to 0.

In the case of the tissue density, there is no distinction between the cortex and white matter in real life. Firstly, the punctured static friction and punctured dynamic friction of the white matter were adjusted to 0.03 and 0.35, respectively (Table 6.2). However, the density of the cortex could not be adjusted as no changes were perceived when modifying these parameters for this structure. The explanation for this is that the capability of the haptic device to compute the haptic properties of an object along a trajectory is limited by the accuracy of the device. In this case, the trajectory of the biopsy needle across the virtual cortex was too small. This suggests that a millimetre separation between haptic objects might not be simulated properly. The expert could not feel the traverse of the biopsy needle during the parameterization. As such, the *puncture static friction* and *puncture dynamic friction* of the cortex were initially assigned values of 0.01 and 0, respectively (Table 6.2). Following discussion with the expert, it would be more accurate to set these values to 0.03 and 0.35, respectively, so that the density of the cortex equals the density of the white matter as in real life.

The expert assessed the generated force feedback as realistic when inserting the needle into the cortex and the white matter (Table 6.3), except for the slight hardness and springiness perceived from the cortex boundary, as previously mentioned.

A similar situation was experienced with the cyst, where no force feedback was detected. Again, its separation with the tumour boundary was small. In real life, only a slight resistance would be felt when piercing the cyst. Therefore, the *pop-through* value, set to 0.09 during the parameterization (Table 6.2), may be set to a lower value so that it is in accordance with the expert's description. In real life, its density is also very low, as this structure is composed of liquid, and as such the *punctured static friction* and *punctured dynamic friction* were also given low values (Table 6.2). During the assessment, the expert agreed that the force feedback when traversing the cyst was realistic (Table 6.3).

In real life, the force feedback experienced when piercing the abnormal tissue depends on the type of tumour. In this sense, analysis of the clinical images to help in the adjustment of the haptic properties of the tumour is essential; MRI scans show the tissue density as a function of the light intensity. In this case, the *pop-through* value was set to 0.09, and the *punctured static friction* and *punctured dynamic friction* values were set to 0.05 and 0.04, respectively (Table 6.2). The expert agreed that the force feedback was realistic (Table 6.3).

Finally, the expert indicated that the insertion/extraction of the inner cannula should not present any force feedback when advancing the inner cannula along the trajectory, as the different tissue properties are noticed only when the outer cannula is inserted. Therefore, it is necessary to programme the haptic interface so that the inner cannula does not detect the haptic properties of the tissue. The expert strongly disagreed with the accuracy of the haptic interaction in this respect (Table 6.3).

### *6.6.2 Assessment of the Anatomical Accuracy*

The degree of realism is also dependent on the accuracy of the elements within the virtual environment. For example, accurate representation of shapes and textures as applied to surfaces, behaviour of the biological tissues subjected to pressure or piercing forces and anatomical detail will enhance the realism of the simulation considerably (van der Meijden and Schijven 2009).

The expert strongly agreed that both the skull's shape and texture were realistic (Table 6.4). However, it was suggested that the inclusion of cranial sutures would greatly enhance the reality of the virtual environment by aligning with these surgical landmarks as in real life. Additionally, the expert advised changing the colour of the skull to a more realistic ivory colour.

The expert also agreed that the shape of the cortex was accurate (Table 6.4), although the sulci appeared too pronounced for the age of the patient. The colour of the cortex was not realistic enough and needs to be adjusted to pale grey/pink salmon. In the case of the white matter, the expert strongly agreed that the shape and texture were realistic. The shape of the cyst was considered realistic too, although its colour should be pale yellow green as in real life. Similarly, the shape of the tumour, with irregular fine surface lobulations, was considered realistic, although its colour should be paler. Textures in line with the expert's description need to be assigned to these models.

The expert strongly agreed that the location of the abnormal tissue was realistic (Table 6.4). The 3D visualization of the anatomical structures in the virtual environment confirmed an extra axial lesion, which was not evident on planar imaging. This demonstrates that the use of 3D visualizations may clarify some information which is not possible to extract from 2D clinical images. Although out of the scope of this study, this fact supports the utilization of Amira or similar software to, for example, pre-plan complex interventions where spatial relationships are confusing.

### *6.6.3 Assessment of the Instrumentation*

Delorme et al. (2012) showed that a variety of short-goal-oriented training tasks starting at one stage of the surgical procedure with increasing difficulty levels enhances the realism of the simulation. Also, the inclusion of articulated/non-articulated and activated/nonactivated surgical tools must be taken into consideration (van der Meijden and Schijven 2009). This prototype represents some of the procedural steps performed in stereotactic brain biopsies and allows controlling the activation of the virtual biopsy needle.

As shown in Tables 6.5 and 6.6, the expert strongly agreed that the models of the stereotactic frame and biopsy needle were accurate. The expert agreed that the mapping was realistic and indicated that the depth at which the biopsy needle is inserted into the guide holder to reach the tumour was correct, as well as the direction, orientation and rotation of the biopsy needle during its manipulation using the haptic device (Table 6.7).

On the other hand, the biopsy needle was not always correctly aligned with the guide holder's aperture when it was inserted into it during the simulation. The reason for this is that the portion of the haptic object which represents the guide holder's aperture was slightly enlarged in order to improve the stability of the haptic interaction (Fig. 6.17), thus creating a region of overlapping between the guide holder and the haptic object. As a consequence, sometimes during the simulation, the biopsy needle goes through the overlapping region, piercing the borders of the guide holder which are supposed to be solid. Therefore, the user may sometimes see the biopsy needle slightly displaced from the centre of the aperture once it is inserted. As previously discussed, the limitations in the accuracy of the haptic device affect the rendering of the interaction with small objects.

It must also be mentioned that the expert found it very difficult to insert the biopsy needle into the guide holder, which is hampered by the difficulty of perceiving the spatial location of the biopsy needle's tip in the 3D space. This is not a difficult step in the surgical procedure and was felt to be a distraction from the purpose of the teaching tool. As previously explained in this study, different perspectives are provided in the top right viewport in Fig. 6.11 in order to help the user guiding the biopsy needle within the virtual environment. However, this is clearly not enough. In order to solve this problem, a stereoscopic visualization of this virtual reality system could be highly beneficial.

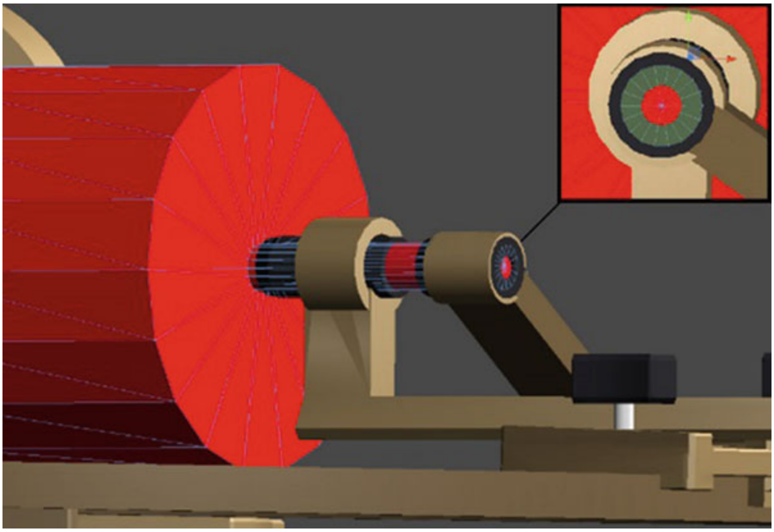


**Fig. 6.17** Guide holder (*black colour*) and haptic object (*red colour*). The overlapping between the haptic object and the guide holder due to the extra enlargement of the haptic object is shown in *green colour*. The *green area* can be pierced by the biopsy needle causing mapping problems which may be perceived by the user

An important feature to be corrected regarding the procedural steps is the order in which the cannulas are introduced into the guide holder. In real life, the outer and inner cannulas are introduced together and not separately as exemplified in the simulator; here the outer cannula insertion is followed by the inner cannula insertion. Therefore, the expert assigned a neutral mark to this feature of the simulator (Table 6.7). Additionally, the expert indicated that the system does not encompass all of the procedural steps necessary for the biopsy needle insertion and sample collection. In real life, the outer cannula can be rotated once it is locked into the guide holder, and the depth of the biopsy needle can be readjusted during the surgery, which allows sampling from a wider region of the tumour. Also, the expert advised the inclusion of a syringe which creates a negative pressure to pull tissue into the side-cutting port of the needle. The realism of the procedural steps was assigned a neutral mark too (Table 6.7).

### 6.6.4 *Future Potential of the Stereotactic Brain Biopsy Simulator*

The planning of the stereotactic brain biopsy procedure and selection of reasonable trajectories, targets and entry points are time-consuming tasks which require careful analysis in advance of the actual neurosurgery. In this respect, a learning tool to help trainees understand these features would be useful, and development along this line must be considered for future work. Additionally, further research concerning more accurate haptic rendering is required.

## 6.7 Conclusions

A methodology for the development of a haptic-based virtual reality simulator to train the motor skills required in stereotactic brain biopsies is presented in this work. This tool has been developed as a proof of concept to explore its potential for neurosurgical training in the insertion of a biopsy needle and sample collection during this surgery. The study includes a parameterization and analysis carried out by an expert neurosurgeon in order to evaluate the suitability of this tool to support surgical training.

The association between risk to patients and surgical training through the *apprenticeship model* requires further study. However, it is clear that a simulator which accurately and efficiently recreates the functionalities of the instrumentation used in stereotactic brain biopsies, and encompasses all the procedural steps necessary for its completion, would help trainees enhance their surgical skills and familiarize them with the different procedural steps and their order before practising on patients in the operating theatre. In this respect, the heuristic study developed for the analysis of this prototype has highlighted some issues to be corrected, for example, the accuracy of the haptic interaction, anatomical structures and instrumentation and the procedural steps represented in the simulator.

Results from this analysis tend towards focusing future work on the accuracy of the haptic interaction. Problems such as the inaccurate rendering of small-size anatomical models or the inaccurate mapping of objects need to be resolved. Also, the feedback provided by the expert regarding the shape and texture of the anatomical structures is very valuable for future work and must be corrected in order to make the visualization correspond with the characteristics of the real tissue. The results of the heuristic study also indicate that rotating the outer cannula and readjusting the depth at which the biopsy needle is inserted, as well as using a syringe to create a negative pressure while the side-cutting port is open, must be included as part of the simulated procedural steps. In addition, the functionality of the tool was hampered by the difficulty of perceiving the spatial location of the surgical instrument, and therefore the development of a stereoscopically haptic training tool would greatly assist the user in guiding the biopsy needle. As such, it might be wise to consider the use of a mirror in conjunction with a stereoscopic display to align visual and proprioceptive workspaces (Viciana-Abad et al. 2011).

As stated in the literature, haptic-based virtual reality simulators afford trainees the opportunity to practise in a safe environment without the legal and ethical concern for patient safety, the limitations of the working time directive and the costs associated with operating theatre time. Moreover, trainees are at a more advanced stage in their learning before attempting procedures on patients, which streamlines operating theatre efficiency. In addition, surgical simulation training allows quantitative assessment of trainee performance through the inclusion of assessment tools and the generation of objective reports. Such tools monitor user progress and improvement in motor skill training for specific tasks, as well as providing validation studies for the implementation of surgical simulators in the training curricula. Having said this, the prototype presented in this work does not include assessment feedback due to project time constraints during development; however, such a feature is desirable for future versions of this haptic-based virtual reality simulator beyond this prototype.

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# Chapter 7
# Interaction and Communication in an Immersive Learning Game: The Challenges of Modelling Real-Time Collaboration in a Virtual Operating Room

**David Panzoli, Catherine Pons Lelardeux, Michel Galaup, Pierre Lagarrigue, Vincent Minville, and Vincent Lubrano**

**Abstract** In this chapter, we describe the methodology we have engineered during the design process of the collaborative and immersive learning game 3D Virtual Operating Room. The game targets an audience of practitioners involved in the operating room and the training consists in virtually re-enacting typical perioperative activities so as to learn or improve skills related to patient safety. The challenges faced in this project include multiplayer collaboration in a shared, interactive and dynamically evolving virtual environment, and modelling educational scenarios on the basis of actual observations inside the operating room. The model we detail is grounded on a semantic definition of the environment which allowed for three innovative features. A game-mediated communication system where information pertaining to the game is exchanged in real time by the players. AI-controlled characters replacing missing players as fully equal partners. And, the ability for the game to provide feedback in real time or during a debriefing on the team's performance against predefined pedagogical objectives.

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**Keywords** Immersive learning game • Design methodology • Multiplayer collaboration • In-game communication • Business process modelling and notation

## 7.1 Introduction

During the eighteenth century, Madame Du Coudray teaches the art of birthing (Rattner 1998) to women across the French countryside. Part of the training relies on mannequins allowing to re-enact several obstetric manoeuvres. It is estimated that during her 25-year education campaign, she has trained over 4,000 midwives, and as a consequence the infant mortality has markedly decreased. Over the next centuries, medicine and medical education have largely benefited from the latest technological and technical advances, owing to their unmatched potential for saving lives.

Simulation is an innovation that unquestionably marked a step forward in education. "Simulation is a technique [. . . ] to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner" (Gaba 2004). Practically, simulation in healthcare education is defined as using an equipment, a computer software, a mixed reality system – which is a combination of both real and virtual – or a standardised patient for replicating a medical environment and/or a healthcare situation. Most commonly, simulators are utilised for rehearsing or practising diagnostic and/or therapeutic procedures. Simulators can also make visible fundamental concepts and thus help gain insights into the inner mechanisms governing a machine (as the virtual anaesthesia machine, for instance) or a biological system. Simulation in medical education offers many benefits. Firstly, it provides a safe, patient-free environment where mistakes can be experimented repeatedly and without causing any harm. Doing so, simulation also allows addressing rare yet critical situations. Secondly, simulations can easily be tailored to a specific curriculum, selected on demand and arranged by a teacher into a comprehensive collection in order to suit one or several given training objectives. Moreover, as the training does not depend any more exclusively on the practitioner's personal experience, simulators bring a form of standardisation which, besides of being a strong asset in favour of equal opportunity, tends to guarantee a good "average level" among the trained practitioners. More advantages of medical simulation are listed in Ziv et al. (2000).

Although simulation has been resorted to since as early as antiquity, the birth of modern simulation is often dated in the early 1960s (Rosen 2008). A modern simulator is computer-driven, runs an anatomically or physiologically accurate model of a human organ or patient and allows interaction with the medical learners (Murphy et al. 2007). Modern simulators integrate various degrees of sophistication: from simple multimedia to three-dimensional virtual reality applications. Those usually provide representations and interactions for task trainers to fully immersive virtual replicas of the clinical environment and the patient, including audio and touch. Virtual reality has available a large spectrum of techniques and devices in order to produce an illusion of reality with more or less believability. For instance, in the field of anatomic simulators alone, Richard Satava (1996) has highlighted the steady evolution of three generations: anatomical modelling (navigation-enabled immersive representation), physical modelling (featuring interactions, deformations and kinematic constraints) and physiological modelling (where the functions of the organ system are introduced). The contribution of VR to simulators is undeniable (Gallagher et al. 2005) and explains why they are now in common use in medical education for training to many different tasks.

One common use of simulation is for learning therapeutic procedures. This can be achieved using a mannequin, like SimMan (Laerdal) and human patient simulator (HPS, CAE Healthcare), both being physical devices yet embedding extra digital features for simulating a large number of vital functions such as breathing, heart rate, blood pressure and numerous patient sounds. Accessories allow for the replication of more specific diseases (flesh wounds, burn marks, etc.). The mannequin can be auscultated, intubated and ventilated; it can undergo a cardiac massage and even endure a defibrillation. Its pulse can be checked in several locations (arm, carotid, femoral artery, etc.). A specific location on its arm can even be given an injection or installed a catheter.

Training to surgical gestures is another context where simulators are used. The laparoscopic surgery training simulator (LAP Mentor, Simbionix) is a mobile simulator composed of several instruments dedicated to laparoscopic surgery and a screen displaying the image simulating the endoscope camera. Each instrument, whose handle is the accurate reproduction of a genuine one, can be manipulated with 5 degrees of freedom. The force feedback reproduces the feel of tissue resistance on the surgeon's hands. The simulator embeds several scenarios of increasing difficulty (stitching, gastric bypass, etc.) and sorted in different learning modules (essential, advanced skills, etc.) (von Websky et al. 2012). Surgery simulators can grow more complex (and more expensive) like the endoscopic sinus simulator (ES3, Lockheed Martin) for endoscopic sinus surgery. The ES3 aims at providing the most immersive experience by combining high-end graphics, haptic controls, a voice recognition, a head mannequin with realistic anatomy and a physical replica of an endoscope (see Fried et al. (2005) for a detailed description). The Vascular Intervention System Training (VIST G5, Mentice) is another example of a large-scale simulator combining physical devices and virtual reality in order to provide the closest possible experience to reality.

The simulators mentioned above are high-fidelity simulators, which means they tend to reproduce the patient or a subsystem with a high degree of realism, both visually and interactively. Yet, high fidelity is not a prerequisite for efficiency in training (Gallagher et al. 2005), and low-fidelity simulators can be used for teaching processes and conceptual knowledge. This is the case for diagnosis and decision-making, which can also be practised using simulators like virtual patients (Cook and Triola 2009). A virtual patient is often presented as a simple text-and-graphics interactive slide show where a case study (possibly spanning through several years using ellipses) is presented as a branching scenario where the learner explores the consequences of their decisions. Another illustration of training to non practical skills is the well-known Virtual Anaesthesia Machine which provides a simplified yet insightful view on the inner operating of an anaesthesia machine (Fischler et al. 2008).

Although simulators are commonly utilised in hospitals for a wide spectrum of educational purposes, a few domains have failed so far to make their way to computer simulation and assisted training. Teamwork and communication training, for instance, are both good examples of what simulators have been unable to provide so far. Teamwork and communication skills are therefore learnt in the hospital using role-playing-based training, organised in small groups, using mannequins like HPS or SimMan mentioned earlier, and under the supervision of an expert trainer. The role of the trainer is somewhat similar to a game master in traditional role-playing. He knows the rules so as to conduct the narrative and lead the team of learners through the scenario, refereeing on their decisions and their impact on the scenario. He provides at the end of the session a collective debriefing, yet pointing every individual good/bad action/decision. Role-played mannequin-based training is efficient, but many benefits of simulation are lost due to the mandatory presence of the trainer, namely, time, cost and scalability. Lee et al. mention additional shortcomings (Lee et al. 2006) related to unwanted yet inevitable variations in the training and limited realism depending on the context (e.g. outdoor intervention, large-scale disaster, etc.).

Fortunately, there is an alternative: serious games. As defined in Michael and Chen (2005) – although many other definitions exist – serious games are games that "do not have entertainment, enjoyment or fun as their primary purpose". In learning games, also called educational video games, the primary purpose is education, although known assets of traditional games as enjoyment, involvement, motivation, creativity and emotion are relied on for the learning to be more effective than in a traditional setting. The history of serious games is unclear and may date back long ago (Djaouti et al. 2011), but America's Army (2002, US Army) is often cited as the first game to have ever combined a demonstrated serious purpose and the level of quality of a triple A game. America's Army is an immersive multiplayer game. Several players are immersed in a shared virtual environment in 3D realistically reproducing a battleground or a training camp and interact with the environment and with each other in order to fulfil missions. In many perspectives, America's Army looks a lot like a medical simulator, saved for the learning objectives which are far from medical training. Luckily, immersive learning games have since explored various application contexts.

Immersive learning games are three-dimensional interactive environments where a scripted experience can be lived by one player or shared by several players in the case of a multiplayer – or collaborative – game. The purpose of a learning game is to use individual (or collective) experience in order for a learner (respectively a group of learners) to acquire new knowledge, gain insight on a process, learn or rehearse a procedure, change habits, etc. This experience, although virtual, must possess all the traits of an actual experience in the workplace.

For this reason, learning games borrow many elements from video games: 3D environments, scripted experiences and feedback. A three-dimensional interactive environment is one of the most common feature of a video game that can be used in a learning game as it provides an immersive experience. Immersion has been demonstrated to be central in learning (Coulter et al. 2007). Dede (2009) suggests that immersion is likely to enhance education in at least three ways. Firstly, a phenomenon or a process is better comprehended and learnt if it can be approached from multiple perspectives. Secondly, immersion allows for situated learning (Lave and Wenger 1991) by providing an authentic experience. Thirdly, immersive experiences replicating the real world are likely to facilitate knowledge transfer (Prensky and Prensky 2007; De Freitas 2006) to a real-world context.

Scripting the experience is another characteristic inherent to most video games. Unlike a simulator which can be seen as a plain tool, a game is never limited to a virtual world. The experience of the player(s) has been formerly thought through by game designers and described in a scenario. Then, the experience is controlled in real time and adaptively by a narrative, which can take many forms but whose goal is invariable. Narrative can resort to complex drama management techniques (Sharma et al. 2010) in order for the experience to be tailored to each user's emotional personality.

Finally, feedback is an important variable in the game equation that becomes even more important in a learning game. Feedback is about letting the player know about the impact of their last decision or their current situation within the game. It can be immediate or diffuse. It may be as simple and explicit as a score or a message displayed on the screen or on the contrary subtle modifications in the game graphics or in the narrative. In a learning game, feedback is used to relate the learner's actions and decisions to their consequences and thus facilitate the learning. It can be used in real time during the game to provide guidance to the learner or at the end of the game as an indicator of global performance to debrief the learner's actions and decisions.

Learning games can be similar to simulators and can even be based on a computer simulator. For this reason, they share most of the benefits of simulators: they offer a safe, patient-free, controllable and reproducible environment; they allow for collaborative learning, unlimited rehearsal of procedures or exposure to clinical cases of interest.

However, there is a significant difference between a simulator and a learning game. A learning game embeds naturally one or several training scenarios and the corresponding rules for evaluating the learners in autonomy. This difference, as illustrated by the iceberg metaphor (Fig. 7.1), has major implications on how the design of a learning game should be approached and particularly how to balance the design between playing and learning. Namely, the iceberg metaphor illustrates how much of the global effort is invested in learning-related aspects, whereas the game (as the final product of the project) only represents a fraction of this effort. Owing to their autonomy of use, learning games are easily accessible to a student audience in the classroom or playing from home. They are also found to be cost-effective in comparison to medical simulators, particularly for their maintenance. Finally, it is admitted that younger generations are increasingly acquainted with

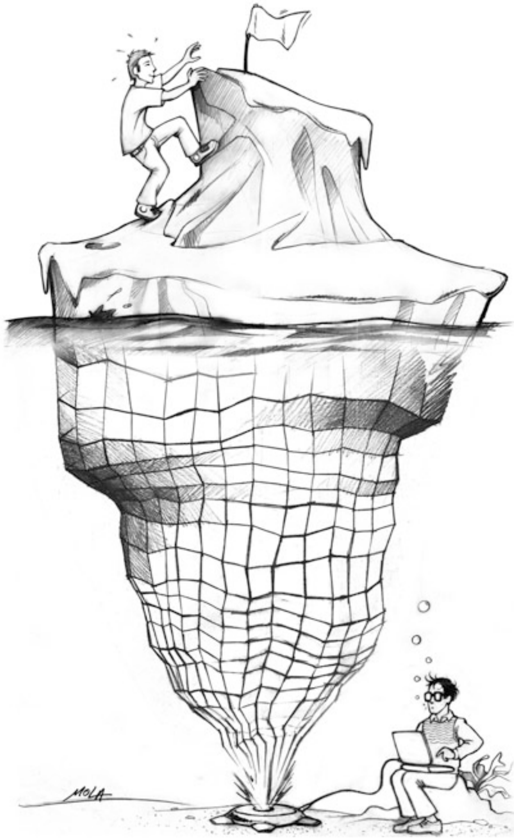


**Fig. 7.1** The iceberg metaphor applied to the design of a learning game. It shows that in a learning game, most of the time spent, the budget and the complexity lie in the hidden part of the design, which relates to every aspect of the learning: identifying the objectives, modelling the scenario, engineering the rules for learner accompaniment and collecting the data for debriefing the learner. From the learner's point of view, the visible part is a contextualised experience, with a well-identified goal, challenging yet attainable and rewarding

game technology, and this new way of learning becomes over the years more an asset and less an obstacle to education (Waters et al. 2008).

How the relationship between simulators and learning games will evolve in the future is very uncertain, as learning games can potentially be used to train both technical and non-technical skills (Graafland et al. 2012). Yet, many learning games designed for training to technical skills are based on a simulator, if only for the sake of accuracy. Conversely, many recent simulators have started incorporating built-in scenarios and user evaluation. For now, an implicit rule seems to state that technical skills (surgery gestures, protocols, etc.) are best practised individually using simulators, whereas learning games seem particularly suited for non-technical skills and collaborative learning. This is especially the case in the 3DVOR project, which targets communication in the operating room.

### *7.1.1 3D Virtual Operating Room*

The 3D Virtual Operating Room project (Lagarrigue et al. 2013) (3DVOR) is a learning game dedicated to improving the communication inside the operating room between the surgeon, the nursing staff and the anaesthetist. Miscommunication accounts for a high percentage of the different failures arising during a surgery (Kohn et al. 2000) and likely to provoke irreparable injuries to the patient or death. 3DVOR is a collaborative and immersive experience, where the learners are expected to follow the procedures of a surgery (protocols, checklists, etc.) from the admission of the patient to the transfer into the recovery room. Doing so, the objective of the game is to highlight the importance of sharing knowledge and maintaining a good assessment of the current situation for the decision-making to be effective, even in emergency situations.

3DVOR is set in a realistic environment where several locations (operating room, pre- and post-operating rooms) have been carefully modelled and furnished (cf. Figs. 7.2 and 7.3). All along a game session, the game monitors the users, guiding them through the scenario and delivering a debriefing at the end of the game. Scenarios allow teams of professionals (i) to re-enact in an immersive and realistic environment numerous situations fictional yet inspired by recurrent routine-induced mistakes or uncommon acute crisis and (ii) to see their response evaluated against prevention and risk management procedures (institution procedures, patient checklist, etc.).


**Fig. 7.2** The academic prototype of 3DVOR has been designed as a proof of concept in order to demonstrate that the methodology could successfully turn a collection of filmed data into a fully operational collaborative learning game. 3DVOR is currently being developed by KTM Advance, Novamotion and Champollion University. Many visual improvements are being brought to the public game, but the underlying model remains very close to this prototype

**Fig. 7.3** The game prototype offers two environments: the admission room (*upper row*) and the operating room (*lower row*). Each can be seen under different perspectives depending on the role played: surgeon, nurse or anaesthetist (from *left* to *right*)

The interaction model proposed by the game to the users is very typical. Users are presented with a first-person perspective of the environment (cf. Fig. 7.2) which reflects realistically the actual locations of the surgeon, the nurse or the anaesthetist. Objects and other characters can be interacted with by means of predefined actions and interactions (open/close a drawer, power on/off an appliance, read a document, ask something to someone and so on). Upon being clicked, an object displays a specific contextual menu listing the interactions as textual labels. Clicking on a label triggers the corresponding interaction, which is expected to have an impact on the environment and possibly entails further interactions. Realistic depictions of the patient's medical record documents are accessible for collecting information about the case under investigation. Finally, learners are also allowed to communicate while playing a scenario using an innovative communication system integrated within the game where information tags can be collected in a panel (rightmost in Fig. 7.2) and shared in real time.

## 7.2 Related Work

Allowing multiple players to play a scenario together is a challenge that has already received much attention, whether or not in a medical context or for a serious purpose.

### 7.2.1 Learning Games Related to Medical Education

vHealthCare (Breakaway Games), formerly known as Pulse!!, is a serious game presented in a realistic and immersive 3D environment. It has attracted a wide press coverage, thanks to a professional production and a colossal budget. vHealthCare's training revolves around the medical competencies required in an emergency situation such as a transport accident or a bio-terrorist attack. To that end, it features a 3D environment inside which the learner is free to move and interact. Each virtual patient is realistically modelled, able to visually simulate a large number of pathologies and thus to train the learner to diagnosis. Procedures, replicated with high fidelity, can be considered as learning objects on their own. Yet, vHealthCare is not meant for learners to play since it does not contain any usable scenario. Indeed, vHealthCare is intended to be integrated in a larger-scale educational project tailored to the requirements of the client.

Clinispace (Parvati et al. 2011) pursues a similar goal: training learners to patient care by means of acting virtual doctors or nurses. Each virtual patient is realistically represented in 3D, and so are all the different environments inside which the learner moves freely (lobby, intensive care unit, patient's room, conference hall, etc.). The game allows multiple players to collaborate, and interactions with the patient or the medical equipment are accessible to each player via a single click (a right click displays a list of available interactions for the clicked object). The game does not feature the ability to include non-playing characters in the environment. The discrete-time progression of the virtual patient's scenario gives way in Clinispace to a continuous simulated evolution of the patient's condition allowed by an unsophisticated yet medically plausible model of a patient's pathophysiology, able to answer dynamically to every treatment (or lack of treatment) by a corresponding evolution of the patient's vital signs. Clinispace's multiple environments allow addressing operational aspects (consult the patient's medical history, treat a patient) as well as organisational aspects (plan a surgery). Players are allowed to converse using either a text-chat or a voice-chat system. The trainer follows the action "from inside" the game, where he can decide to guide the scenario and talk to the players, play the role of the patient or remain invisible for observation only. Whichever way he is involved in the game, the trainer has the responsibility of debriefing the learners. This is done outside the game, on the basis of his observations throughout the scenario. Regarding the scenarios, the game is bundled with a limited number of them (one trauma and a few infection cases), and each trainer is expected to model their own educational scenarios.

Team Training in a Virtual Interactive Environment (3DiTeams, Taekman et al. 2007) is a similar serious game in the context of an emergency unit. Part of the game revolves around the transmission of patient-related information from their admission in the emergency unit to their stabilisation. The game scenarios deal with competencies from the TeamSTEPPS curriculum. The game is technically grounded on the HumanSim framework and the GO Platform. HumanSim embeds the physiological model responsible for the patient's behaviour. GO Platform enables the 3D game to run on a web browser. Up to 32 learners can join the virtual emergency unit, including the instructor who can, for example, brief the team with his avatar at the beginning of a game session. Upon the patient's arrival, learners start formulating assessments, make diagnoses and engage in therapeutic procedures. The patient's reactions are controlled either automatically by the physiological model or by the instructor using a dedicated interface. The session ends when the patient is stabilised. The learners are virtually gathered for a performance debriefing led by the team manager on the basis of session recordings.

Second Life (SL, Linden Lab) is an open virtual world frequented by a massive audience of users worldwide. Environments in SL are highly customisable, visually and functionally. SL users are allowed to build objects and attach scripts to them for controlling their behaviour, whose complexity ranges from simple interactive objects to chatting virtual characters (chat-bots) depending on the user's programming proficiency. Using SL for training to medical skills has been successfully attempted on several occasions, SL has been successfully used for training to medical skills (Lee and Berge 2011). Notably, researchers at Imperial College London have built a virtual training facility in SL where students can independently (e.g. a trainer is not required) practise to diagnose virtual patients, train to prepare themselves for a surgery and learn to manipulate medical equipment in the operating room. The scenario for each educational activity is implicitly defined through the scripted behaviour of the objects throughout the virtual hospital: furniture, equipment or interactive messages on the walls or on the floor. Practising diagnosis involves conversing in natural English with a chat-bot patient preprogrammed to give answers coherent with a predefined illness. Commonly, chat-bots in SL run internally a program using pattern matching (i.e. syntactic analysis) to detect keywords in the users' questions and find the most appropriate answer accordingly.

Safe Surgery Trainer (Alion, Synensis) is a one-player serious game focused on effective communication and protocols towards improving patient safety. The game is centred upon communication regarding the safety of a virtual patient and expects the player to learn how to communicate efficiently with other healthcare professionals involved in the perioperative period of a surgery. Several characters are represented within the virtual operating room (surgeon, nurse, patient, etc.), and the player is free to play anyone of them, the others being controlled by an artificial intelligence. The communication features branching dialogues presumably written by or with the assistance of domain experts in patient safety. When conversing with a non-playing character, the player must choose between a set of pre-written sentences which are questions expected to be relevant to the situation or answers that must be carefully chosen. The dialogue with the character is scripted so that any choice leads to another, in a tree-like manner.

### *7.2.2 Interaction, Communication and Scenarios*

The subject of having one or several players interacting in a shared environment and following predefined scenarios has been approached many times antecedently in the history of games and virtual reality applications. Invariably, we notice that interaction, communication and the scenario are three key elements to model in such a collaborative space.

#### 7.2.2.1 Interaction Design

The general model for interaction, undisputedly adopted in virtual environments and immersive games, is inherited from Gibson's affordances theory (Gibson 1979). This psychological theory has been widely influential to the computer graphics community and brought to many implementations, the most famous being smart objects (Kallmann and Thalmann 2002). Smart objects are virtual objects whose description includes visual or interactive properties (what do I look like? How should I be interacted with?) but also the behaviours of both the object and the agent interacting with the object once the interaction is triggered. In addition, smart objects broadcast their interaction abilities to the users, so the interactions can be presented and selected graphically inside the virtual environment.

This type of interaction can be made readily available should the game be based on an existing rich virtual environment, like Second Life (Warburton 2009; De Freitas et al. 2010), OpenSim or cyberworlds of the like. Affordances on the objects can be relatively easily programmed using a proprietary scripting language (Linden Scripting Language in SL), and thus a fully interactive environment can be easily obtained. The simultaneous immersion of several users is allowed out of the box since it is a founding principle of a cyberworld. For the same reason, the communication between several players is allowed and taken care of using an included text-chat console, or voice-chat, should the computer be properly equipped.

One major drawback of using an existing virtual environment is that scenario authoring is far from intuitive, although Bellotti et al. demonstrate how a virtual world can be enriched with authored educational tasks and therefore turned into a serious virtual world (Bellotti et al. 2010). The main source of trouble comes from the absence of an overall coherence in the virtual world, as attaching a script to every object throughout the environment does not really allow to describe how these objects relate to one another or how one interaction with an object is likely to change the states of other objects around (for instance, in the operating room, one immediately thinks of the patient and the monitoring equipment). Surprisingly, the answer to this problem is found in a classic game from 1985, Habitat (Lucasfilm Games), an innovative and influential multiplayer online virtual environment, often recognised as the ancestor of virtual communities. Several insights into how cyberspaces (or virtual worlds dedicated to host several users) should be designed are given by the creators of the game in Morningstar and Farmer (1990). Particularly, an "object-oriented data representation is essential: the basic objects from which you build the system should correspond more-or-less to the objects in the user's conceptual model of the virtual world, that is, people, places, and artefacts". ExploreNet (Hughes and Moshell 1997) is an interesting implementation of this approach. It features an online multiplayer virtual world in 2D where educational activities are designed for a young audience. The object-centric environment of ExploreNet is composed of many objects, some of them being interactive props endowed with an autonomous behaviour (this includes the non-playing characters) and others merely backdrop objects. The behaviour attached to an object is composed of four parts: preconditions that must be true for a behaviour to be carried out, the name of the behaviour for reference, the visual animation associated to the behaviour and the changes resulting from performing the behaviour. Finally, the behaviour of an object can be triggered by means of clicking an action label visually attached to this object.

Building the game from scratch using a game engine (like Unity3D for Clinispace or Unreal Engine for 3DiTeams) instead of an existing cyberworld entails no limitations on expressiveness but certainly requires a hefty amount of computer programming skills. A centralised model of the environment can be integrated so as to provide enough consistency for several players to interact simultaneously with the objects. Anyway, the question of how the scenario should be modelled and integrated in the game remains as challenging as for cyberworlds.

#### 7.2.2.2 Scenario Integration

The traditional "environment-centred" approach consists in an implicit distributed design where the scenario is expressed through the behaviours of the objects. Obviously, it takes a lot of experience and there is no methodology to facilitate the process.

Other techniques have extended ExploreNet's logic. In the multi-agent system used in the learning game Format-Store (Mathieu et al. 2012), every single object in the environment – whether character, item or furniture – is modelled like a software agent and therefore endowed with an autonomous behaviour. As a result, the interactions between multiple human players, non-playing characters, items and the environment are by essence easy to model and offer a great potential in terms of adaptivity and expressiveness. However, scenario authoring, even if possible, suffers from the same shortcomings than the other approaches centred on the environment. Recently, Orkin et al. have described an original approach in Orkin and Roy (2007) where a fully interactive environment, namely, a virtual restaurant, is made accessible for thousands of human players to explore freely. Based on the collection of their actions, a machine learning approach is applied in order to build the statistically realistic behaviour of the virtual employees. Provided that enough training is applied (i.e. enough sample data is collected), this technique shows very promising results. Although it is not possible to design a scenario per se, this technique should allow training one or several artificial characters to imitate a human tutor.

Putting the scenario at the centre of the design process is certainly an alternative way for facilitating the process of pedagogical design. Branching scenarios are very fashionable nowadays in e-learning applications. It is basically a generalisation of the branching dialogues technique mentioned earlier. A branching scenario is designed like a tree structure where every action from the player leads to selecting a branch. Responses from the environment or the virtual characters can be inserted in the scenario using the same structure. However, the approach is not suited for a multiplayer experience. Interactive storytelling (Göbel et al. 2009; Porteous et al. 2010; Sanchez et al. 2004) extends the scenario modelling possibilities and makes use of artificial intelligence planning to manage the dynamic progression of the scenario. In both cases, the approach works well for one unique player but is not applicable to multiple players. Indeed, multiple players' and rich player expression reduces the ability for the author to think ahead and model every situation, note Rield et al. (2011), and therefore it is foreseeable that the scenario will derail at some point. They propose to enhance a non-branching narrative with a Petri net-based system creating branches on demand to handle the exceptions.

#### 7.2.2.3 Natural Communication

Communication in the game or in the virtual environment, depending on their objectives, can either be central to the design or an inessential functionality. Either way, we notice that communication must always compromise between traceability (i.e. How much does the system understand?) and naturalness (i.e. How close to natural speech is the communication system?).

Obviously, the most natural communication system that comes to mind is natural explicit communication outside of the game, meaning talking to each other. Voice-chatting through headset and microphone is a very common way to let people communicate and the first step towards traceability, since this interface makes it easy for the game to record the communications (for later playback). Understanding natural language in real time to use it inside the game is, however, far from trivial for a computer, let alone understanding the context and the meaning of each utterance. Natural language understanding (NLU) is the research domain associated to these questions, and the evidence is that it is still experimental research. NLU techniques are still considered prone to recurring failures compromising traceability. Yet, a handful of successful usages of NLU in a game must be noted. Mori et al. (2013) describe a virtual application where the user is enabled to talk to a virtual character representing a famous Italian painter. More impressively, in the game Façade (Mateas and Stern 2004), the player can converse naturally with a couple of virtual characters and would get an appropriate response most of the time. These examples suggest that such a system could as well be used for debriefing a game session, however unreliably. Besides, related domains of application like embodied conversational agents, which are virtual agents able to demonstrate verbal and non-verbal communication (Cassell 2000), and conversational intelligent tutoring systems (Rus et al. 2013) have reported significant advances in natural language processing techniques, and the benefits of using them are increasingly advocated (Hennigan 2012).

Still, to date, two options seem to prevail, depending on how critical is communication with respect to the objectives of the virtual experience.

Usually, most games focusing on communication skills and teamworking use a voice-chat system and knowledgeably give up on the possibility to automate – even partially – the debriefing. This is the case for Clinispace and 3DiTeams inside which the human supervisor must be part of the game in order to listen to the conversations and use them for debriefing the players once the session is over. When the conversations need to be understood, chat systems are probably a more flexible alternative, since the voice recognition stage is unnecessary. Yet, understanding the content remains as much a problem, and most systems are limited to keyword recognition, like in chat-bots. Chat systems are nonetheless very common in games. Historically, Lucasfilm's Habitat (Morningstar and Farmer 1990) was the first game to allow multiple human players to communicate in a shared virtual environment via text-chatting. In medical training, in the Indiana University Medical School Virtual Clinic (Johnson and Clary 2008), one can converse with a virtual patient in order to investigate their condition and formulate a diagnosis.

In a general way, text-chatting can be assumed to be an acceptable way to enable communication with other players or with the system. It is nevertheless less natural than natural speech and less efficient since it keeps the player's hands busy from actually playing the game. Moreover, natural communication with a computer system is an illusion since only keywords are important.

The second option consists in using branching dialogues. The system is very common in single-player adventure games to design the dialogues between the player and a virtual interlocutor. Each line of dialogue calls for several responses from the player, each of which continuing the dialogue the same way a tree is being explored by an algorithm. Obviously, the drawback of this technique is the work required to think ahead and write every line of dialogue. This is even more complex when both the interlocutors propose several choices. Therefore, in a multiplayer context, not only is the task Herculean, but it seems near impossible to provide for every discussion that the players are likely to engage in, even in a restrained context where the topics of discussion are controlled. Despite the limitations of this technique, traceability is optimal since the objects manipulated have been designed in advance and are therefore known and easily recorded. Predefined dialogues are therefore frequently in use in learning games where communication is central to the game objectives, like in Safe Surgery Trainer.

## 7.3 Objectives

From spanning existing work related to immersive and collaborative experiences dedicated to training or leisure, several observations can be made. Firstly, it seems relatively easy to engineer an immersive and interactive world where several players can be trained collaboratively. Yet, it remains complex to incorporate the scenario of this training in such a way that the game is able to monitor the training on its own or at least reach some degree of understanding of the situation so as to facilitate the task on the trainer's side. The main reason for that is that there is no existing methodology advising on how to link the scenario to the environment and, namely, to the objects undergoing the user's interactions. Secondly, communication is another difficulty very often overlooked in existing projects or treated as a system dissociated from the requirements of the scenario and from the information spread throughout the virtual environment. As a result, communication between the learners offers no traceability: it can neither be used by the game as assessable data nor referred to by the learners to manipulate information about the environment.

Based on these considerations, we have established a list of requirements which we think are key to the successful design of 3DVOR.

- In order for the training to have the most impact, the game must be designed as an immersive experience virtually reproducing with accuracy and consistency the daily routine of an operating room, yet allowing for some unusual perturbations to challenge the player's ability to cope with the unexpected (although in safe conditions). Accurate reproduction encompasses visual fidelity, appropriate interaction abilities with the virtual environment and expressive and meaningful means of communication between the players.
- Multiplayer virtual collaboration must be at the centre of the design, so that people meant to work together in their professional life can be trained together, keeping in mind that everyone in the operating room has a different set of tasks and competencies.
- The game must also be prepared to withstand the unavailability of one or several players: when necessary, artificial intelligence techniques must be deployed for non-playing characters (NPCs) to replace the missing human players on demand and without impeding the remaining players from completing the scenario's objectives. To that end, those NPCs must be considered as fully equal partners (FEPs) (Thomas and Vlacic 2008), not only in the capability to understand the communications and the actions of the learners but demonstrate the ability to participate in those communications as well.
- The game must be provided with some intelligent tutoring subsystem able to keep track of the team's progression within the scenario and to understand the actions and decisions of every player so as to guide them in real time towards the objectives. Besides, this tutoring system should also be able to debrief the team at the end of a scenario, recapitulating the successes and mistakes both on individual and collective levels.
- The pedagogical activities in which the players will engage must be described with enough detail and comprehensiveness for the tutoring system to follow the team's progression and for the NPCs to behave as realistically as the human players and to communicate with as much expressiveness. Firstly, this entails having at hand an explicit description of every individual or collaborative action, communication or decision composing a scenario. Secondly, each one of these

should be attached with a pedagogical “value” reflecting however good, bad or neutral this interaction is, keeping in mind that timing is an important factor for evaluating how pertinent an interaction.

- Variety should be able to be modelled in the scenario’s description (or at least implicitly allowed), as many routes are likely to lead to the objectives with equal soundness. However, unrestricted freedom granted to the players in the environment ought to be balanced with what maximum combinatorial complexity the game is able to cope with.
- Finally, the interactions offered to the players (in terms of action, communication and decision) must be channelled within the boundaries of what can be automatically understood by a computer Although this seems a fairly easy task considering the actions performed inside the virtual environment, addressing the communication reveals more tricky, as, for instance, text-chat and voice-chat, which are traditionally used in multiplayer games, offer very limited intelligibility to the program. Alternative systems must therefore be provided, for the design of which a trade-off between traceability and expressiveness must be sought.

Those challenges have implications weighing on the design of the scenarios and on the interaction abilities offered to the players. The next sections are dedicated to presenting the methodology we have developed with the aim of fulfilling every requirement of a multiplayer collaborative immersive learning game as per the standards we have defined so far.

## 7.4 Game Design Methodology

The gamification process we have applied in 3DVOR is rather straightforward and seems well adapted to collaborative training in a technical context (such as an operating room). Teammates collaborate to re-enact pedagogical scenarios inspired by daily activities in a virtual reconstruction of their workplace. Each scenario is thought as a detailed description of how a specific issue is standardly addressed (e.g. described in the procedure or as part of best practice) or should be addressed ideally. The issues addressed have been carefully identified and listed on the basis of official documents reporting the most frequent sentinel events in the operating room on a national scale and from many interviews with local expert trainers or professionals. As a result of this preliminary work, each scenario in 3DVOR is the fictitious result of the integration of a classical sentinel event into a sequence of routinial collaborative activity.

### 7.4.1 Identifying the Objectives

Sentinel events are unanticipated events in healthcare likely to lead to the patient's death or a serious injury. Basically, leading the learners to experience sentinel events in the game is the objective of the training. Sentinel events in the operating room are well known by medical trainers and the medical community (Lingard et al. 2004). Sentinel events usually result from a communication failure or a bad decision, taken collectively on grounds of expired or inaccurate information or, worse, taken without consensus by one caregiver (namely, the surgeon or the anaesthetist) on the sole account of hierarchical superiority. These events hide among the many tasks and procedures which compose any surgery operation. It is therefore crucial for a scenario to represent the mass of legitimate actions, communications and decisions unthreateningly made, exchanged and taken during the process of the surgery.

How does such a sentinel event arise? James Reason (Reason and Reason 1997) and his "Swiss cheese model" have helped a lot understanding human error in complex systems. Reason distinguishes between active failures, committed by people in direct contact with the system, and latent conditions, caused by bad decisions from managers or procedure writers. Latent conditions are not necessarily mistakes but rather structural parameters bound to facilitate mistakes sooner or later. These are out of the scope of 3DVOR since it is beyond the responsibility of the targeted audience to change the rules in application inside the hospital, although it is important for them to be aware of the existence of such mistakes in the making. Active failures on the other hand are directly targeted by the game objectives. A sentinel event is rarely the consequence of one failure, or is it only in appearance. Very often, analysing a sentinel event reveals several failures committed by different people on different levels. It is also admitted (Reason and Reason 1997) that preventing a single one of these failures to be committed is sufficient to prevent the sentinel event to arise at all.

For instance, one classical sentinel event dealt with in several scenarios in 3DVOR is wrong-site surgery (WSS). WSS is defined as surgery performed on the wrong side or site of the body, on the wrong patient or the wrong surgery performed (Carayon et al. 2004). It is all in all a rare event, but the impact can be devastating, which is a shame considering it is a preventable medical error (Currie and Hughes 2008). Two major procedures have been widely enforced in hospitals to lower the risk of WSS: the checklist and the time-out procedure, both carried out at the beginning of the operation, before anaesthesia. The checklist is inspired from aeronautical preflight procedure. It consists of having the nurse collect information from the patient (name, site, surgery, etc.), corroborate it with the patient record and other document pertaining to the operation (planning, anaesthesia record, etc.) and finally tick the corresponding boxes. The time-out procedure is a collaborative decision taken by the team seconds before the incision. It looks like Go/No-Go questionnaire where the critical information is confirmed out loud one last time before there is no cancelling. Both these procedures rely on a good communication between the team members as (i) the information required is scattered through the environment (people, documents, etc.) and (ii) every piece of information is not necessarily accessible to everyone. Although it seems reasonable to think that these procedures are beneficial to the patient's safety, their added benefit is unclear to the caregivers (Kwaan et al. 2006). On the other hand, they experience daily how these procedures increase the complexity of their job. As a result, these procedures are often met with scepticism, if not rejection. As a matter of fact, they are ineffective if not applied with dedication. And for this to happen, caregivers must firstly understand the interest of the procedure and then learn how to communicate efficiently. A collaborative and interactive game scenario is a good way to show how silent discrepancies can insidiously pass through the procedures undetected and rapidly lead to a sentinel event. That way, the game in general offers a way to experience a mistake we know every caregiver will (statistically) face once in their career, given that this mistake is better committed virtually during the training than in real life with a real patient. Also and more importantly, the scenario offers a way to teach or rehearse the safety procedures and the related communication skills which are hard to teach out of context.

Every scenario is therefore designed to be explored freely by the players, so that mistakes and/or bad decisions can be made without the game interfering. However, during a debriefing session at the end of a scenario, the mistakes committed must be raised and penalised by the game and relevant decisions and actions conversely rewarded. To make this possible in 3DVOR, a full methodology was developed in order to reproduce training scenarios inside a collaborative virtual environment.

### *7.4.2 Representing Human Collaborative Activity*

What does a surgery operation look like? Classically, it includes several stages: patient admission, anaesthesia, surgery and recovery. Obviously, every surgery is unique, and a hip replacement surgery is different from a laparoscopy, but the distinction essentially concerns the actual surgery. All the protocols related to patient safety are little different from one surgery to another, and they are present at every stage of the operation. For instance, WSS is checked during admission and before anaesthesia; during the actual surgery, the patient's safety can be threatened if a nurse in the non-sterile area accidentally enters and contaminates the sterile area. After the surgery, instruments, compresses and needles must be counted before the patient leaves the OR to ensure none was forgotten inside the patient's body. All these routine tasks are important for two reasons: they directly affect the patient and they are repeated many times a shift.

The patient's medical record plays an important role is a surgery as well. It includes all the necessary information pertaining to the patient: medical history, medical allergies, letter from the surgeon, anaesthetic record, MRI images or X-ray radiographies, etc. The patient's record is important all along the surgery, to confirm the identity of the patient by corroborating information from different documents, to confirm the type of surgery by comparing to the surgery planning for this room, or later on the surgery to avoid complications if some medication must be administered to the patient in emergency, should an adverse event arise.

During the surgery, information is crucial, and ideally, every caregiver in the OR should have an up-to-date and exhaustive consciousness of the situation at all time. Unfortunately, and for several reasons, this is seldom the case. Firstly, the situation changes continually, and caregivers focused in their respective task are prone to miss the frequent updates. When routine breaks, in the unfortunate case of a sentinel event, a recovery procedure must be engaged. In that case, a shared understanding of the situation must be reached quickly by the team for the procedure to be applied with efficacy. Secondly, the information is not always available to everyone. For instance, the documents are not physically accessible to caregivers in the sterile area. Clinical data on the anaesthetic record may be understood by the anaesthetist only. The surgeon, while operating, is likely to notice a problem minutes before the other caregivers around.

As a consequence, situation awareness and communication are critical to the smooth running of a surgery, and therefore caregivers must learn to collect information, to judge how important it may be to the team, to circulate it accordingly and eventually to use it appropriately to take collaborative decisions.

In 2013, surgery operations were recorded by the knowledge managers of the project. The set-up was fairly important: two fixed video recorders were placed in the OR. One operator was filming using a third mobile camera for close-ups. A GoPro-type action camera was tied to the surgeon's forehead (see Fig. 7.4) so as to collect a first-person view of the operation. Several hundred hours combined were recorded for further analysis. A set of four representative operations were filmed during a 1-year period: neuroma surgery, hip replacement, laparoscopy and cataract surgery. Within this period, the films were played back, analysed and digitised into computer data by two knowledge managers, assisted by trainers and healthcare professionals.

We have chosen to specify the data using the Business Process Modelling and Notation Graphical Representation (Allweyer 2010) (BPMN). Although it is particularly adapted for modelling business processes, as stated by the name, it works equally well with any collaborative process, like activity in the OR as it happens. The syntax of the BPMN notation is simple: rectangle-shaped boxes

**Fig. 7.4** Dr Lubrano (in the background) being recorded while performing surgery with his team at Toulouse Hospital

represent activity nodes, circles represent event nodes and edges represent flow sequences linking nodes to each other. Each BPMN diagram describes a sequence of activity, where activity nodes are arranged in several lanes, representing different roles, inside a pool. It is designed and read from left to right chronologically. A unique "Start" event node represents the entry point of the sequence. One or several "End" event nodes represent the outcome(s). In between, activity nodes are connected with one another by flow sequences, establishing a relationship of order which should not necessarily be interpreted as a strong constraint. For instance, A→B does not mean that A must be completed before B. It merely indicates that, with respect to our observations in the OR, A has always (or most of the time) been completed before B. However, if nothing prevents completing B before A, then the player re-enacting this activity should be allowed to. Of course, the question is irrelevant if action B is "physically" or logically impossible unless A has been achieved. This question is addressed when connecting the actions and the environment, in Sect. 7.4.3.1. Modelling situations more complex than unconditional linear plans of actions is possible using another element of the BPMN syntax: gateways. Basically, we used two of them: the parallel gateway (+), for coordinated activity, and the exclusive gateway (×) to express choice and alternative. A gateway can be found after one action and opening to several actions or paths of action. In that case, it means the activity is about to face a collaborative sequence (parallel) or alternative paths (exclusive). When the sequence is over, another gateway is placed to mark the end of the sequence. This one acts like a control barrier, and the activity cannot be carried on unless one path (exclusive) or all the paths (parallel) has/have been followed first.

To facilitate the collaborative work involving people from many scientific disciplines, and further scientific communication with a broader audience, we have defined terms for describing the activity that will be used henceforth unambiguously. A sequence (a BPMN diagram or a part of a BPMN diagram) describes the activity of one of several healthcare professionals. The activity is composed of interactions (activity nodes in the BPMN). Interactions can be (i) actions performed on the environment, on the objects or on the patient, (ii) communication or information exchanged with teammates or (iii) decisions taken collaboratively with other teammates.

Figure 7.5 exemplifies a sequence of collaborative activity modelled using a BPMN diagram. Although it is possible to give a label to each activity node in the diagram, we have externalised the labels in a separate table (refer to Table 7.1) to clarify the diagram. Table 7.1 also shows that every interaction is related to an actor in the OR. When an interaction can be performed by several actors, it must be duplicated into several interactions (with the same label and content) each associated with one actor. This may be seen as a restrictive design constraint but has beneficial implications on the AI (typically when one or several roles are assumed by non-playing characters) and on the tutoring system (when each learner's actions must be evaluated).

The scenario modelled by the diagram is a toy example, but all the features necessary for understanding the BPMN modelling process are represented. The

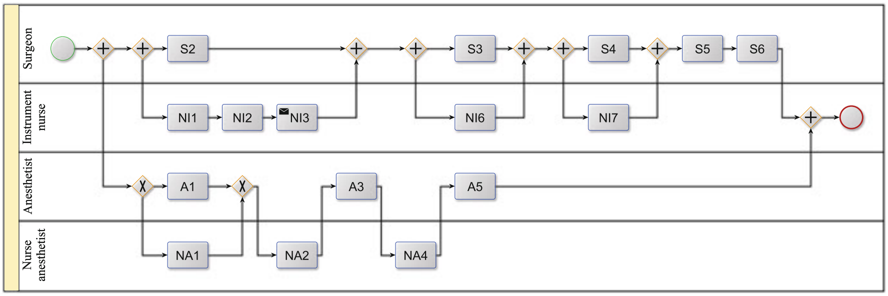


**Fig. 7.5** The Business Process Modelling Notation enables the description of sequences of actions for several actors. Parallel (+) or exclusive (×) gateways are also used to model plans that must be achieved in parallel or plans excluding one another. The example of this figure describes a sample activity used for demonstrating our methodology. The label of the actions can be found in the Table 7.1

**Table 7.1** Description of the interactions from the sample scenario of Fig. 7.5. For the sake of demonstration, this example only shows a simplified set of actions merely inspired from the actual and much more complex procedure

| Character | ID | Description |
|---|---|---|
| Surgeon | S1 | Display radiographies |
| | S2 | Wash hands |
| | S3 | Put on gloves |
| | S4 | Put on mask |
| | S5 | Adjust chair |
| | S6 | Set up lamp |
| | S7 | Put radiographies on desk |
| | S8 | Grab radiographies |
| | S9 | Take off gloves |
| Instrument nurse | NI1 | Grab radiographies |
| | NI2 | Display radiographies |
| | NI3 | Tell surgeon radio are set |
| | NI4 | Put radiographies on desk |
| | NI5 | Light on radiography light box |
| | NI6 | Help surgeon to put gloves on |
| | NI7 | Help surgeon to put mask on |
| Anaesthetist | A1 | Set up monitoring equipments |
| | A2 | Prepare drugs |
| | A3 | Fill perfusion |
| | A4 | Install perfusion |
| | A5 | Anaesthetise patient |
| | A6 | Throw away drugs |
| Nurse anaesthetist | NA1 | Set up monitoring equipments |
| | NA2 | Prepare drugs |
| | NA3 | Fill perfusion |
| | NA4 | Install perfusion |
| | NA5 | Anaesthetise patient |
| | NA6 | Throw away drugs |

diagram is divided into four lanes, each one representing a role in the collaborative activity: surgeon, instrument nurse, anaesthetist and nurse anaesthetist. The scenario reads as follows: The surgeon washes his hands, while the instrument nurse displays the radiographies on the light box and informs the surgeon. Then, the surgeon puts on surgery gloves and a mask, assisted by the nurse. Finally, the surgeon sets up his surgery environment, adjusting the chair and setting up the lamp. In the meantime, either the anaesthetist or the nurse anaesthetist sets up the monitoring equipment. The nurse prepares the drugs. The anaesthetist prepares the perfusion. Then, the perfusion is installed on the patient by the nurse, and the anaesthetist sedates the patient.

Although fictional and simplified, this scenario reveals some invariable characteristics of the activity in the OR. We observed that the caregivers were working in pairs. The activity of the surgeon and the instrument nurse is most of the time collaborative. The anaesthetist and the nurse anaesthetist, however, seem to be interchangeable, and most of the time, any anaesthetic-related interaction can be performed by either one of them.

#### 7.4.2.1 Depth and Extent of a Scenario Content

The illustrative example provided above is not representative of the complexity of an actual scenario, which can neither be illustrated nor quantified. To give an order of idea, the BPMN diagram of a neuroma surgery (a non-cancerous tumour in the brain) has necessitated more than 350 actions, for the only nominal path. The video clips used for modelling each scenario are extremely detailed. During the modelling process, the first challenge is to determine the appropriate level of detail required for the game. We have identified three variables that should be questioned: coverage, granularity and density.

##### Coverage

How much of a surgery should a scenario span? This question has a direct impact on the duration of the scenario, yet defining the span of a scenario is less a question of time than a question of content. Firstly, it is tricky to guess the actual duration of the scenario before it is implemented in the game. Secondly, ellipses can be used if necessary to skip pedagogically uninteresting sequences of the surgery. Thus, content must lead the design, and more specifically interactions or sequences of activity unquestionably related to the scenario objectives must be identified (e.g. what actions, communication or decisions can really allow telling if the skill has been mastered or the knowledge acquired). A scenario is therefore built on the basis of an extract from the description of the whole surgery, targeting in time one specific moment of a surgery. This extract is called the "nominal path" since it describes the activity observed on the video, when the surgery runs through as expected. On the time span of the nominal path, systemic risk events provoked by inappropriate interactions or hazardous events likely to happen under certain circumstances must be identified and integrated. Each one of these events occurring in the game can either lead to a game over (scenario is interrupted and the team sent off to debriefing) or to a "degraded path", a fork from the nominal path associated with a near miss that can be recovered provided an efficient communication is deployed and the right actions and decisions are taken. In that case, the recovery routine that potentially leads back on the track of the nominal case must be described using the BPMN format and integrated within the scenario. Due to their inherent unusualness, the interactions of the recovery routines are likely not to be observed on the surgery operations filmed during the collection process. Therefore the degraded paths must be designed by hand with the help of expert trainers or healthcare professionals. Figure 7.6 illustrates another toy example scenario (interactions are anonymous) where the nominal path includes one potential hazardous event (the yellow circle on the BPMN of the nominal case) leading to a degraded path (the recovery procedure) which contains a plan of interaction for recovering the mistake and landing back on the nominal course of the surgery.

### Granularity

The granularity of the interactions is related to how precisely the players are expected to interact with the environment or exchange with each other. Fine-grained granularity meticulously reproduces virtually every gesture, behaviour or information exchange observed in the OR. As a result, the game delivers an accurate simulation of each task. On the other hand, the game difficulty rises proportionally as missing one interaction or doing it wrong becomes more probable. On the opposite, coarse-grained granularity frees the player from low-level attention and focuses them on staying aware of the situation and thinking ahead. On the other

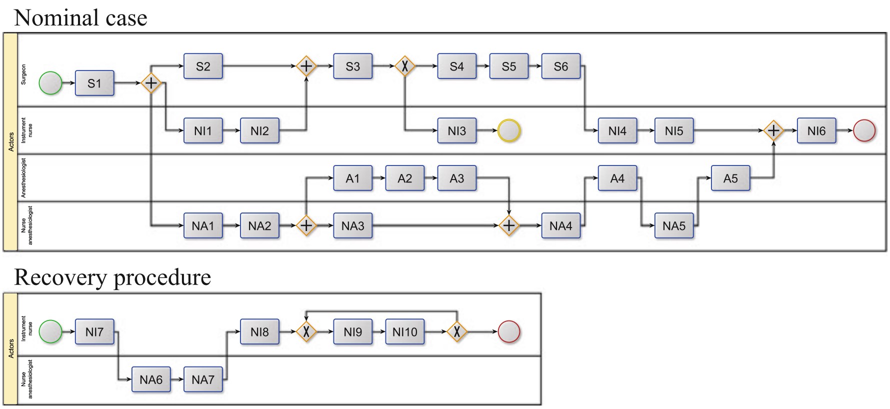


**Fig. 7.6** A game scenario is an extract from the BPMN description of a surgery, where hazardous events, selected for their relevance to the objectives of the scenario, have been placed and their potential recovery procedure described

hand, mistakes, near misses and faulty behaviour are less likely to happen as the freedom of action is decreased. Naturally, we want the granularity of the interactions to be set somewhere in between. In practice in 3DVOR, each surgery video has been sequenced into discrete interactions following a rule of common sense: every interaction must unambiguously mark a change in the environment (turn on an appliance, open a door/drawer, etc.) or to a player (gear up, collect/receive new knowledge, etc.).

Density

Finally, density reflects how much of the observed interactions in the OR should be actually integrated as part of the BPMN modelling. Considering that the BPMN description of a surgery is the result of several observations, some interactions are likely to be observed every time, and others may not; some interactions are likely to be considered important, and others may appear as optional, unrelated to the operation or even futile. As a result, a choice must be made regarding how much of this inessential activity must be reported on the scenario. Integrating too few of these interactions clearly directs the players towards the correct way of achieving the scenario, lowering the challenge and therefore the efficacy of the training. On the opposite, too many of them unfairly distract the team from achieving the objectives by making too many interactions available in the environment. Density, as granularity, has revealed very hard to adjust beforehand and has necessitated in 3DVOR going back and forth between designing and testing each scenario.

#### 7.4.2.2 Scenario Validation

Once a scenario has been designed, or during the course of the design process, two types of validation can be carried out. Both are important at this stage because they can substantially lighten and facilitate later user testing of the game by detecting obvious deadlocks, inaccuracies in the scenario or hidden flaws in the narrative that beta-testers would be unlikely to encounter.

The first form of validation is content validation. It aims to ensure that the content of the scenario is coherent with respect to the activity captured in the first place and actually reflects the original objectives of the scenario. Content validation of a scenario relies on domain experts reviewing the activity described on the nominal and the degraded paths. Thanks to the BPMN graphical notation, this form of validation has revealed intuitive and effective, as errors or ambiguities resulting from misunderstandings were pointed out by the experts.

The second validation process deals with eradicating possible incoherences, dead ends or infinite loops that could structurally prevent the players from reaching one or several objectives of the scenario. To achieve this process, we have engineered an automated method (unpublished yet) based on the use of formal grammars. The rough idea is to replace each action by a production rule and to develop the grammar from a start symbol representing the initial state of the scenario until expectantly reaching the end symbol representing the final state of the scenario. The method is similar to algorithmic validation, only applied to BPMN models.

### *7.4.3 Digitisation of the Activity*

Digitising the activity consists in turning the sequences of activity identified and modelled in the previous sections into virtual, immersive, interactive and collaborative experiences. The digitisation process is technically challenging for several reasons: Firstly, the interactions described as part of the activity are intended to be performed at the same time (or within the same time span) by several players in the same environment. Secondly, the interactions available to the players must be presented to them within the virtual environment, so as to maintain the immersion of the players. Thirdly, non-playing characters, replacing missing players or acting uninteresting roles, should be granted the same level of understanding of the situation and the same interaction abilities. These challenges have called for a step-by-step methodology, pictured in Fig. 7.7 as a bell-shaped curve emphasising the abstraction process of actual activity into a computer model used for designing concrete experiences in the virtuality. The steps of the process are detailed in the next paragraphs.

#### 7.4.3.1 Grounding the Actions: The Semantic Environment

The computerised human activity held in the BPMN diagrams cannot be used straightforwardly as a digital experience since the computer can neither understand the interactions labelled on the activity nodes of the BPMN diagram nor relate them with their expected impact or meaning in the environment. The process of anchoring

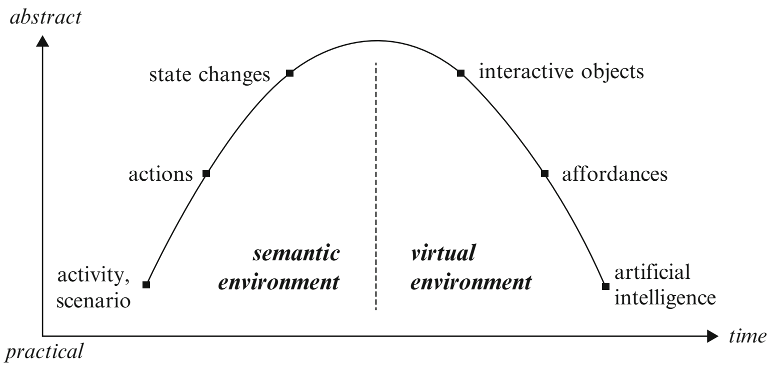


**Fig. 7.7** The process of turning scenarios modelled from observed activity into an immersive, interactive and collaborative virtual environment where players and non-playing characters can interact with each other must be decomposed into several steps. The pivot of the process is the automated creation of a semantic environment

the interactions into a semantic environment is a necessary step towards solving that problem. What we refer to as a semantic environment is a set of variables representing the states of every object mentioned in the activity and therefore to appear in the virtual environment for the players to interact with (the word object will henceforth refer indifferently to furniture, equipment, document, character, patient, etc.). Thus, the semantic environment is a pivot in the process of turning described activity into an interactive virtual world.

As far as we have detailed the modelling process, interactions are the atomic pieces of the description of activity. Therefore the anchoring process shall be applied independently to every interaction. The idea is to characterise every one of them in terms of actual, noticeable or measurable changes applied to objects in the environment. In the next paragraphs we focus on the actions only, as communication and decision are characterised differently since they have no measurable impact on the objects in the environment.

Specifically, each action is described as a set of changes of the form *object.attribute←value*. For instance, an action labelled "Anaesthetise patient" should be translated as *Patient.asleep←true*, meaning the attribute *asleep* of the object *Patient* has been assigned the boolean *true* as new value. We can also imagine that, as a side effect of this action, the anaesthesia syringe pump has been emptied and therefore adds to the translation: *Syringe_pump.contains_anesthetic←false*. We could also imagine that the same action could have implications on monitoring equipment or many other objects, depending on the granularity of the action.

Describing the effects of an action highlights a problem related to the conditions under which the action is available. For instance, in the example above, let us say that the patient cannot be anaesthetised if the syringe pump is turned off. This matter leads us to consider that preconditions to an action should also be described along with the effect. The result is illustrated in Fig. 7.8 showing the XML description of the action mentioned above once the preconditions have been set. In contrast with preconditions, effects of the actions are now called postconditions.

Preconditions have a dual role. Firstly, and most importantly, comparing in the game the preconditions of an action with the actual state of the environment

```xml
<action id="A5" actor="anesthetist, nurseAnesthetist">
    <label>Anesthetise patient</label>
    <preconditions>
        <pre object="Patient" attr="asleep">false</pre>
        <pre object="Syringe_pump" attr="on">true</pre>
        <pre object="Syringe_pump" attr="set">true</pre>
        <pre object="Catheter" attr="open">true</pre>
    </preconditions>
    <postconditions>
        <pre object="Patient" attr="asleep">true</pre>
        <pre object="Syringe_pump" attr="c_anesthetic">false</pre>
    </postconditions>
</action>
```

**Fig. 7.8** Every action from the BPMN graph must be described in terms of changes of states of objects in the environment. Objects can refer to furniture, appliances, documents or people will decide whether or not this action is available. Secondly, preconditions can be used for telling a legitimate action apart from a sentinel event. In the example given above, imagine we add in the scenario another action bearing the exact same label but with different effects: for instance, one precondition becomes *Syringe_pump.set=false* and one postcondition becomes *Patient.asleep←false*. This new action is clearly a sentinel event where the anaesthesia will fail due to a negligence with the syringe pump. If during the scenario the team has carelessly forgotten to set up the pump, the "counterfeit" action will underhandedly be presented to the players instead of the legitimate one, leading to a sentinel event should the action be actually performed.

Once all the actions of the diagram have been detailed as explained in the paragraphs above, a list of all the state changes can be collected from skimming the actions (this process is easily automated). The information held in this list is nothing less than the description of the environment inside which the players will re-enact the scenario, only this environment is not yet virtual but semantic, which means focused on the meaning of the activity rather than on the graphics. Figure 7.9 shows how the "raw" semantic environment can be reworked into a more readable diagram using the UML class diagram syntax elements.

Although in principle, the value of an attribute may be of any type (e.g. integer, character string, etc.), we used in practice boolean variables only. The reason is explained in Sect. 7.4.3.3.

#### 7.4.3.2 Making of the Interactive Environment

The semantic environment provides a meaningful description of the virtual world. Yet for the players to use it, it has to be represented accordingly in the virtual environment. Specifically, every object from the semantic environment should be given a visual representation. This process is necessarily manually performed by 3D modellers. However, working with an object-oriented programming language greatly facilitates the process as it provides a framework for the objects to be designed. In an object-oriented programming language, the programmer manipulates objects. Each object is instantiated from a class, which describes the objects by their attributes and their methods. Attributes of an object define its characteristics. Methods, to simplify, are functions describing how the object can be manipulated by itself or others.

In a graphical application, these software objects can be associated to graphical elements. If the object is to be displayed graphically, then attributes may define a shape, a colour, a size, etc. Attributes of the object in the semantic environment can therefore be given a meaning in the virtual environment. To that end, each attribute in the semantic environment (like *Patient.incised* or *Patient.monitored*) is reflected by an attribute in the Patient class. Moreover, the (boolean) value of each attribute of a class has an impact on how the objects instantiated from this class are displayed, for instance, by parametrising their location, their mesh or a texture, etc. This is illustrated in Fig. 7.10 with two attributes belonging to the patient. Following the

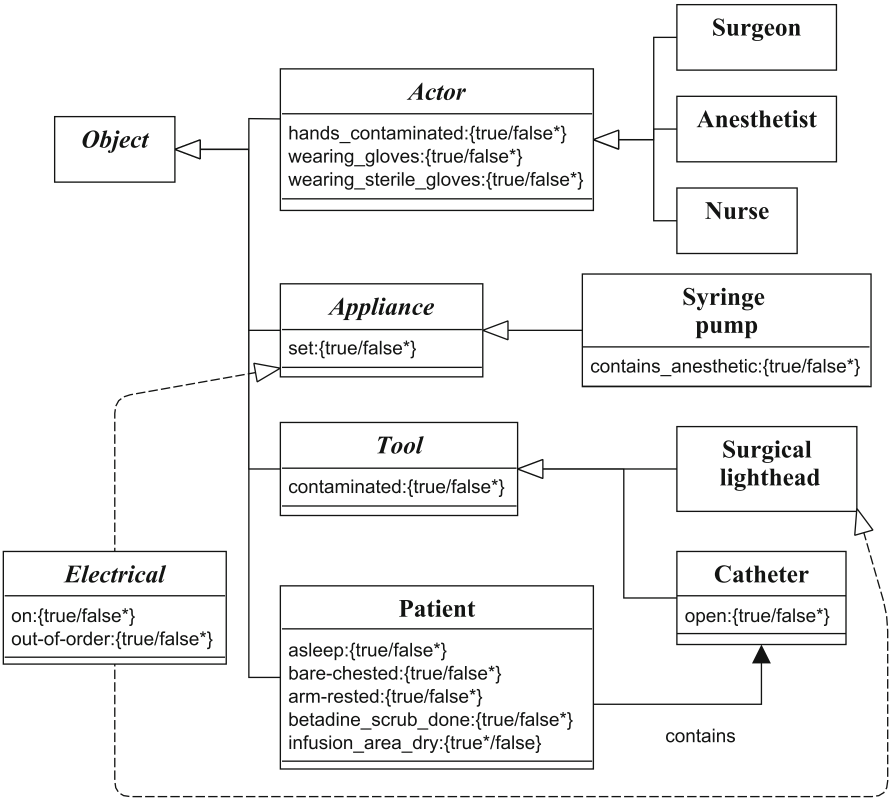


**Fig. 7.9** The raw list of objects and attributes collected from the actions can be reworked and refactored to resemble the traditional UML class diagram. This way, the information is more clearly read, and potential mistakes in the descriptions (typos, doubles, etc.) are more easily found and mended

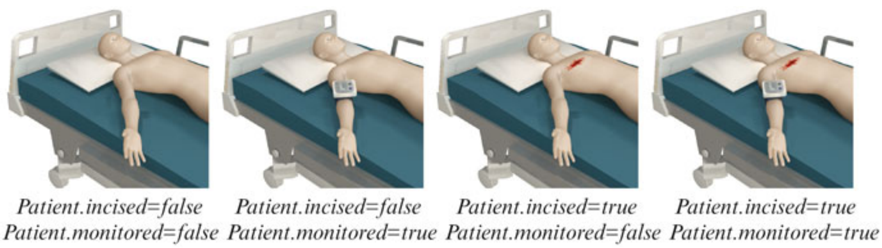


**Fig. 7.10** Software objects in object-oriented programming are related to objects from the semantic environment. The attributes of these objects are related to visual cues whose graphical representation reflects the value of each attribute. This way, the semantic environment can be projected in the virtual world effortlessly

same idea, methods can be associated to behaviours describing how the object can change or be modified. In Unity3D, for instance, which is the game engine used in 3DVOR, visual objects in the graphical scene are represented by software objects in JavaScript or C# associated with a mesh, a material, a texture, a matrix defining a position and a rotation in space and other components like colliders for helping with the interactions. In the academic prototype of 3DVOR (cf. Fig. 7.2), JavaScript was used along with an HTML/CSS home-made environment, and the process was almost identical:

1. For every object in the semantic environment, a corresponding class must be programmed in the game engine.
2. For every object in the semantic environment, a 3D model must be designed and associated to the class.
3. For each attribute of the object in the semantic environment, a corresponding attribute must be defined in the software class representing the object.
4. Methods must be programmed for changing the attributes of an object. Graphical animations or visual modifications (changing the texture, the lighting, the size or the position of the object) must be integrated within those methods so as to make a modified attribute reflected by a graphical modification in the virtual environment.

Changing the states of the objects requires setting new values to their attributes, and this is done by means of calling the appropriate methods of the objects. The players are neither allowed nor given the ability to call these methods in the game. Instead, they are required to use the interactions described in the BPMN diagram. Each interaction (as discussed in Sect. 7.4.3.1) is described as a list of state changes, and therefore selecting this interaction is the right way to perform the related changes. Having a player select and perform an interaction is nothing complicated provided this interaction can be presented to the player in a user-friendly way. Since the game is set in a virtual environment, the interactions should therefore be given a graphical representation. Actually, the traditional way to do so in virtual reality is to attach the interaction (for instance, as a floating label or as an item in a contextual menu) to the object(s) concerned by this interaction, what is referred to as an affordance (Gibson 1979) on the object. In Fig. 7.2, the screenshot shows the contextual menu listing the available interactions for the anaesthetist on the anaesthesia trolley. Finding the object(s) concerned by an interaction is as easy as listing the object(s) mentioned in the description of the interaction. At each time step during the game (i.e. each time the environment has been updated), the virtual environment runs through this simple algorithm:

1. Obtain from the game the list of all available interactions, as per the actual state of the semantic environment and the preconditions mentioned in every interaction.
2. Filter the interactions with respect to which character is playing (each player runs its own version of the game, although synchronised with the others).
3. Attach those interactions to the objects in the virtual world, for instance, in a contextual menu or as floating labels.

4. Wait for the player to select an interaction.
5. Process the interaction, update the environment and start the loop over.

Each interaction having an effect on the environment, starting over the loop after each interaction, involves re-evaluating the set of available interactions for each player, and so the scenario unfolds.

In order for this to work technically, a client/server architecture must be used. The role of the server is to hold the data representing the semantic environment. Centralising the semantic environment is very important to avoid having to cope with discrepancies when several players interact with their own version. In 3DVOR, the JavaScript-based environment *node.js* was used for the server logic. The server also manages the communication with multiple clients. Each client embeds the graphical environment reflecting the semantic environment and scripts managing the computer interactions between the player and the game. Since the game is immersive, the virtual world is displayed differently on each client, depending on the point of view of their avatar inside the environment (cf. Fig. 7.3). Yet, although each player perceives the world from their own point of view, the world displayed is the same for everyone.

How is the synchronisation managed? Every time an interaction is selected by a player, the client informs in real time the server by sending a message. The server analyses the interaction and updates the semantic environment as per every state change described in the interaction. The list of those changes is then broadcast to all connected clients, including the sender. Upon receiving the changes, each client synchronously calls the associated methods on the concerned objects which contain the visual effects or the animations to cast on the virtual environment. That way, each time one action is performed by a player, it is instantly noticed visually by everyone. The back-and-forth communication between the client(s) and the server is on average in the order of 8–10 milliseconds in a local network, which is barely noticeable by the players.

As we mentioned in the previous section, communication and decision are two types of interaction processed differently from actions. If qualifying an action in the environment can be achieved by listing the changes in the environment resulting from this action, applying this argument to exchanging information or making a decision is absurd. Communication is all about the information exchanged and not about how the objects in the environment are affected when one player talks to another. Yet, we have made our point in Sect. 7.2.2.3 that traceable communication was an important feature in a learning game, especially when communication is at the centre of the game objectives. We have also emphasised that communication between learners should be mediated by the game for the information exchanged between the learners to be taken into account by the game. In 3DVOR, we have engineered a communication system where information was given a tangible and visual form. Pieces of information are represented as tags in the virtual environment. Tags of information are collected from the objects in the environment (the patient, medical equipment, documents, etc.) using interactions described in the BPMN diagram, stored in a memory panel representing the knowledge of a character and exchanged between the players. Interaction metaphors have been designed to allow manipulating the information: sending, asking, corroborating and making decisions. Collaborative decision-making is featured in 3DVOR by a real-time graphical activity where learners can express their opinion and argue using information tags as supportive arguments. This innovative communication system is described in detail in Lelardeux et al. (2016) along with a primary evaluation of the system with several groups of student nurses playing a scenario related to patient identification. What is also discussed in further detail in Lelardeux et al. (2016) is the fact that the content of the information tags is directly issued from the semantic environment. Statements like *Patient.asleep=true* or *Surgeon.wearing_glove=false* are states of the semantic environment, but they can just as well be used as pieces of information pertaining to the environment, and whose value do not actually reflect the actual state of the object concerned but a belief, that can be accurate or not. Beside the communication system, information can be used in preconditions to actions to represent the fact that knowing or ignoring an information has an impact on the span of actions available to a learner.

#### 7.4.3.3 AI Control for Non-playing Characters

In a collaborative game where scenarios are intended for several players, there is a chance that not all the required players are available. Despite the absence of one or several players, the game should enable the remaining players to be trained, ideally replacing the missing players by non-playing characters (NPCs), which are actually controlled by an artificial intelligence (AI) program. Besides, AI-controlled players could also be used for playing pedagogically uninteresting roles in the scenario, like a nurse outside the OR called for occasionally to supply consumables or replace a deficient tool.

For the other players to be unaffected by their interactions with NPCs, the game design should make it a priority giving the NPCs the same capabilities for interacting in the environment, communicating with the other players and making decisions. In Thomas and Vlacic (2008), fully equal partners (FEPs) are defined as intelligent entities able to cooperate with other FEPs (human or artificial), each one not being necessarily aware of the nature of their partners. Thus, in order for the NPCs to be considered as fully equal partners, the same reasoning capabilities as human players are required from them. Obviously, current knowledge on AI has not equalled the capacities of human cognition, and creating artificial entities able to understand their environment, creating knowledge on their own and using it for performing tasks and following objectives are still a very challenging matter. However, in a well-defined and delimited context, like in a game where the interactions are simplified and the objectives explicit, AI techniques have demonstrated their aptitude for providing a believable imitation of the mechanisms of human cognition. Several techniques can be used, that can be categorised into two different paradigms: the agent-centred approach or AI planning. In 3DVOR, we have explored the AI planning approach. The AI developed for controlling the NPCs in 3DVOR (Sanselone et al. 2014) is

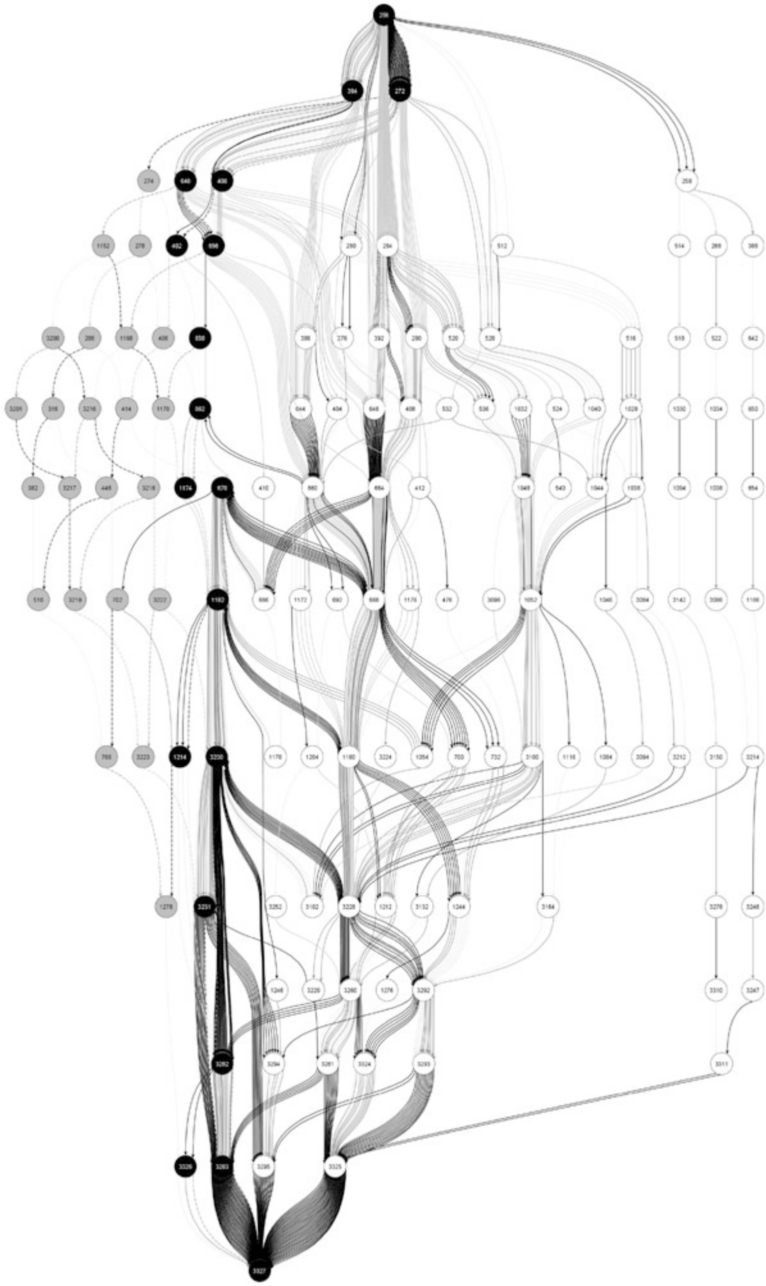

**Fig. 7.11** Graph statistically showing the result of 100 runs of a sample scenario. Circular nodes correspond to states of the environment. *Black nodes* belong to the scenario and therefore should be visited. Conversely, white nodes do not belong to the scenario and should not be visited. *Edges* correspond to interactions undertaken by the characters, leading from one state to another. The four shades of *grey* correspond to the four character roles in the scenario, from *black* to *light grey*:

grounded on the Monte Carlo Tree Search (MCTS) algorithm, a dynamic planning algorithm demonstrated to cope well with very large search spaces. The algorithm is very similar in concept to traditional chess-playing algorithms, where a tree-like structure is built to explore and evaluate the alternate moves potentially chosen in turns by the player and the AI opponent. When a team of learners is engaged in a virtual collaborative activity, the AI algorithm calls for some adjustments and optimisations to cope with the increased complexity, but in essence completing collaboratively a scenario of 3DVOR is little different than ending a chess game.

The algorithm builds an internal graph-like representation of the possible ways the scenario is likely to unfold. Figure 7.11 illustrates such a structure on the scenario presented in Fig. 7.5.

Each node represents a different situation. A situation defines a state of the environment, which is represented internally by a vector aggregating the values of each attribute of each object in the environment (where each attribute is always found at the same index in the vector). The fact we assumed every attribute to have a boolean value significantly facilitates encoding each state as a vector of boolean, which can be easily translated as an integer number (cf. the numbers labelling the nodes on Fig. 7.11). The edges of the tree represent the interactions performed by the different roles (this is illustrated in Fig. 7.11 by the different grey shades). From each node, several available interactions can be explored and lead to new situations (nodes). Different interactions are likely to lead to the same node, for instance, when the same interaction performed by different characters obviously leads to the same result or when two different paths where the same interactions have been performed in a different order lead to the same situation in the end. For this reason, the structure maintained by the algorithm is a graph and not a tree as in a chess-playing algorithm. The graph is oriented and initiated by a node representing the initial situation described in the scenario. Following the actions described in the BPMN diagram, the graph should end with one final node. In practice, there can be several ending nodes since situations can be different but still equally compatible with the activity described in the scenario. For instance, two situations where the surgery is successfully completed and the patient stitched can be different because of the light box on the wall being switched on or off. The state of the light box makes those two situations being considered as different nodes on the graph, but it certainly does not change the outcome of the scenario.

Building the structure is facilitated by our methodology since it closely relies on the ways the semantic environment is modelled and the activity is described. Applying the algorithm on the structure is an automated, dynamic and asynchronous process which consists in anticipating the situations the team will reach and being

**Fig. 7.11** (continued) surgeon, anaesthetist, instrument nurse and nurse anaesthetist. During the 100 runs, the AI has succeeded every time planning a series of action from the initial state to the desired final state. Yet, the great variety in the paths taken suggests some of them are different from the BPMN description and therefore may not appear as realistic able to decide which are the most appropriate actions. In concrete terms, the AI aims for the team of learners and NPCs to follow at the closest the nominal path of the scenario, as described in the BPMN diagram. To that end, the AI starts by building a first graph (the black nodes on Fig. 7.11) which can be seen as the backbone of the structure. Yet, as soon as the game starts, the scenario can unfold in several ways, one of them being the nominal path and the many others being alternative paths enabled by the fact that several interactions are actually available (despite one only being actually favoured in the BPMN). The AI will therefore anticipate the other routes and build dynamically a thicker graph around the first one (the white and grey nodes on Fig. 7.11) by exploring the situations (nodes) to which these unplanned yet possible interactions lead. As soon as a node is added in the graph, it must be evaluated in order to measure how desirable it is to guide the team towards that situation. Evaluating a situation does not require the AI to have any understanding of it but simply consists in calculating the minimum Hamming distance from the node to every black node (e.g. any node from the nominal scenario); the lesser this distance, the more suitable the situation.

During the game, it is very unlikely that the human players will follow closely the scenario described in the BPMN. Firstly, they do not have the knowledge of the scenario. Secondly, real-time collaboration makes it hard for the game to guess in what order the interactions will be performed. Therefore, the role of the AI is to cope with the disturbances inevitably brought by the human players. This necessitates anticipating the unforeseen situations the team will reach and constantly guiding them back on the tracks of the nominal scenario. Having at each time the knowledge of the best next action(s) to perform, the AI has two ways of making its voice heard. NPCs, if there are any, are easily commanded which interaction to perform since they are controlled by the AI. Thus, the AI uses the NPCs to steer indirectly the whole team. Naturally, the human players cannot be controlled the same way. Nonetheless, the AI can still reach to them using explicit messages individually or collectively displayed on the players' screens or hints in the virtual environment, like highlighting the object(s) concerned by the next most appropriate action. The fact that every action's (other forms of interactions like communication or decision are not concerned) description mentions the objects impacted facilitates such a feature.

## 7.5 Scenario Gamification and the Tutoring System

We covered so far the steps required to reproduce human collaborative activity on a multi-user computer simulation using a relatively simple computer model. We mentioned in Sect. 7.3 that the main objective of a training session consisted of a team of learners to explore freely a pedagogically elaborated scenario and to be evaluated at the outcome. The scenario progresses as the learners perform interactions in the environment, until reaching an outcome of the scenario, positive or negative. As we made clear in Sect. 7.4.1, the reasons of a failure are often more complex than pointing out the learner who last performed an interaction.

Respectively, it works the same way with the reasons of a success. Therefore, however successful or failed a game session, the whole progression should be put under examination if real responsibilities are to be established. For this reason, the gamification process consists in marking some of the interactions as of pedagogical interest so that actions or decisions can be understood by the game as positive or negative with respect to the objectives of the scenario and therefore rewarded or sanctioned accordingly. Every type of interaction is likely to be of pedagogical interest: action, communication or decision. Therefore, forgetting to communicate important information to a teammate is likely to be blamed as much as missing an action on the patient.

How are these actions linked to the objectives of a scenario? Figure 7.12 illustrates the description of one of the objectives of the scenario related to WSS: cross-checking the identity of the patient in order to avoid operating the wrong patient. This is a top-level objective of the scenario (rightmost box in Fig. 7.12). A scenario can contain several of them, but they require to be independent (patient security, checklist procedure, etc). A top-level objective is decomposed into lower-level sub-objectives, following a divide-and-conquer strategy. The emerging structure is a tree diagram where each node is a composite sub-objective – save for the root which is the top-level objective – whose fulfilment is tied to objectives of lower rank and complexity. Pooling the objectives can be guided by a thematic approach (for instance, group all the objectives related to patient safety, regardless of their position in the scenario) or chronological coherence (group all the objectives

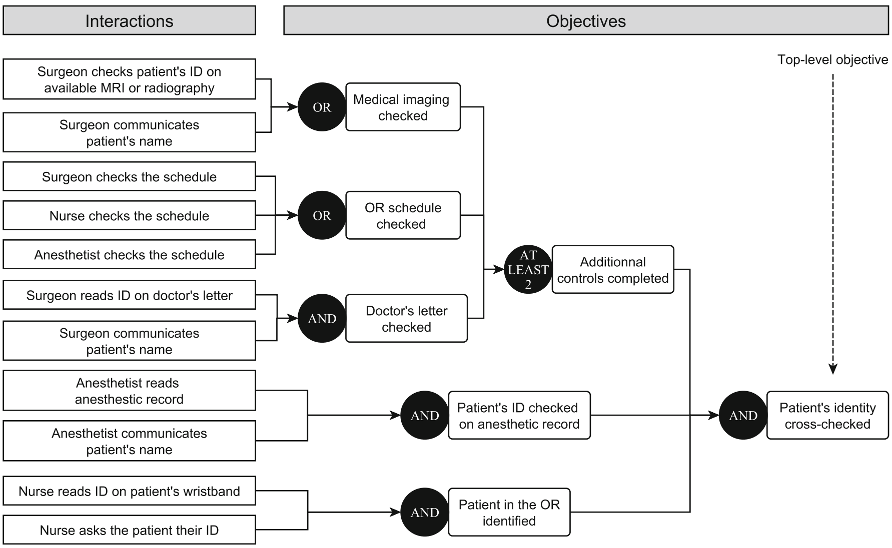


**Fig. 7.12** The objectives of each scenario are developed in a tree-like structure where the root is the main objective (there can be several top-level objectives in a scenario, hence several trees) and the leaves are actions watched by the game. The sub-objectives of the tree enable the high-level description of pedagogical logic

related to a procedure). Finally, at the other end of the tree (on the left in Fig. 7.12), the leaves reference interactions of the scenario that must be watched by the game. In essence, gamifying a scenario consists in building a tree structure on top of existing interactions of the scenario. Not all the interactions in the scenario have to be linked to an objective and therefore categorised as good or bad. It is understood that many interactions in the description of activity have a null impact on the evaluation of the player or the team. As a result of this process, each gamified scenario can be regarded as an orthogonal structure (Duval et al. 2015) where the description of the activity crosses the description of the pedagogy at right angle, the interactions being the common elementary units of each model.

As the game advances and the learners interact in the virtual environment, the pedagogically marked interactions are being watched by the game.

Triggering them leads to completing the related sub-objectives, taking into account the logic associated. The black circles in Fig. 7.12 illustrate some of the available logic elements used to express complex relationships. For instance, a sub-objective can be completed once all the related actions have been performed or once one of the related interactions has been performed. Conversely, other objectives can be considered completed by default and become "missed" if one or several interactions are triggered, in the case of near misses or sentinel events, for instance. Completing sub-objectives can lead to completing higher-level objectives following the same logic and so forth until the top-level objective is completed eventually.

Completed or missed objectives are detected in real time by the game so that instant feedback ("Congratulations! you just completed the objective ...") or guidance messages ("You should focus on the objective ...") can be delivered to the players to keep them motivated or to let them know if they are on the right way. At the end of the session, all the objectives can be reviewed individually and collectively during a debriefing session where each learner is presented a summary of the objectives of the scenario along with corresponding scores and possibly including graphics. High-level objectives can indeed receive a score (for instance, like a percentage) to reflect the level to which the corresponding skill is considered acquired. An objective can be partially completed if, for instance, it is composed of three sub-objectives, only two out of which having been completed. In that example, the objective would be completed at 66%. Similarly, multiple objectives allow for pointing out the strong or weak points of an individual. For instance, within the same scenario, a learner can score high on the top-level objective related to a protocol (executed perfectly from beginning to end) while showing gaps in another objective related to patient's safety along the surgery. Finally, it is worth mentioning that the average percentage of completion of every top-level objective of a scenario can define a score for this scenario, to compare with other learners.

The supervisor/trainer is encouraged to take place in this debriefing session in order to give clarifications regarding missed or failed objectives or additional feedback helping the team understand how they could have improved their performance. We also have observed that the trainer was representing an authority who was more likely than the game to help the learners endorse the failures pointed by the game or accept the outcome without blaming the game.

## 7.6 Conclusion

In this chapter, we have described a design methodology applied to an immersive and collaborative learning game named 3DVOR. Although 3DVOR situates the action in the operating room, we argue that the methods and results reported in these pages can be transferred to any context related to collaboration and communication in the workplace. We believe the role of this methodology is to structure and bring coherence to a set of processes independent from one another in appearance, but actually deeply intertwined as every choice has implications in every aspect of the game. In a shared virtual environment featuring the realistic reconstruction of an operating room, several users assuming the roles of healthcare professionals play pedagogical scenarios spanning the different know-hows involved in patient safety during perioperative surgery. Based on actual footage in the operating room and interviews with expert trainers, each scenario is the actual reconstruction of collaborative activity enriched with pedagogical objectives used by the game to assess the performance of the learners re-enacting the activity. The connection between the activity described in the scenarios and the interactive virtual environment where objects, equipment, documents and the patient evolve dynamically is managed almost automatically owing to a powerful yet simple representation scheme. Communication is also mediated by the game owing to an innovative system where information pertaining to the scenario is generated by the game and provided to the players to manipulate graphically and impact theirs actions and decisions. Finally, missing players can be replaced by non-playing characters whose actions and decisions can be controlled by an AI system merely from the data of the scenario.

Owing to the coherent representation of the objectives, the activity and the communication, the game is able to organise on its own a debriefing session where each active mistake is unravelled so as to show learners that a sentinel event is often the result of multiple causes and involves several actors at various degrees of implication.

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# Chapter 8
# VR Surgery: Interactive Virtual Reality Application for Training Oral and Maxillofacial Surgeons using Oculus Rift and Leap Motion

**Yeshwanth Pulijala, Minhua Ma, and Ashraf Ayoub**

**Abstract** VR Surgery is an immersive virtual reality operating room experience for trainee surgeons in oral and maxillofacial surgery maxillofacial surgery. Using a combination of Oculus Rift head-mounted display, Leap Motion tracking devices, high-resolution stereoscopic 3D videos and 360-degree videos, this application allows a trainee to virtually participate in a surgical procedure and interact with the patient's anatomy. VR Surgery is highly useful for surgical trainees as a visualisation aid and for senior surgeons as a practice-based learning tool. This chapter discusses the need for reforms in the existing surgical training methods and a brief review on simulation, serious games and virtual reality in surgical training. Following this, the principles of design and development of VR Surgery are presented.

**Keywords** VR Surgery • Oculus Rift • Leap Motion • Orthognathic surgery • Surgical training • Mixed reality • Immersive reality • Virtual reality • 360-degree video

## 8.1 Introduction

According to a Lancet report released in 2015 (Meara et al. 2015), 5 billion people in the world lack access to safe and affordable surgery. To meet this challenge, an additional 2.2 million surgeons, anaesthetists and obstetricians are needed in the next 15 years, which is unlikely to happen with the current methods of surgical education (Meara et al. 2015).

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Conventionally, surgical residents learn through observation and hands-on participation in the operating room sessions following a structured training programme. This process, termed as Halsted's method of learning (Kerr and O'Leary 1999), has been in practice for more than a century now. Gradual changes in the learning methods led to the introduction of more hands-on approach where surgical trainees assist and perform parts of the procedure under the guidance of an experienced surgeon (Reznick 1993). In addition to these sessions, trainees undergo rigorous practice in surgical skill labs to improve their manual skills including hand-eye coordination. In spite of all these training methods, four out of every ten novice surgeons are not confident in performing a major procedure (Rodriguez-Paz et al. 2009, Geoffrion et al. 2013). Further, overcrowded operating rooms, reduced training hours and poor visibility of surgical site are multiplying the intensity of their problem. The VR Surgery project was designed to meet this need in surgical training by providing cognitive training for maxillofacial surgeons.

This chapter explains the VR Surgery project and its role in enhancing surgical education. It is divided into three parts: the first part elaborates on the existing methods of surgical training and need for their transformation; the second part reviews the application of simulation, serious games and virtual reality (VR) techniques for surgical training purposes; and the third part outlines the design and development process and challenges encountered in the VR Surgery project. It is then followed by a discussion on the current state of immersive experiences available for surgical training.

### *8.1.1 Surgical Training and Its Challenges*

Surgical training comprises of two major aspects, namely, technical skills and non-technical skills (Yule et al. 2006). Technical skills are those manual skills required to perform the surgery, which are learned traditionally through mentoring and hands-on practice (Satava et al. 2003). The majority of the existing surgical training suites focus more on the technical skills (Wingfield et al. 2014). However, studies concerning major mishaps in operating room have found that the underlying causes for the errors are poor non-technical skills of the surgeons (Bogner 1994; Fletcher et al. 2004, Dedy et al. 2016). Non-technical skills include interpersonal communication, cognitive skills and diagnostic and decision-making skills, amongst others. Lack of proper cognitive skill training beforehand was found to cause major mishaps in the operating room (Wingfield et al. 2014). Some researchers (Aggarwal et al. 2004, Hull et al. 2012) have highlighted the potential application of non-technical skills training in future simulations. A study on teaching in operation theatres by Roberts et al. (2012) suggested that even though the technical skills can be mastered in skill laboratories and virtual simulations, teaching within operating room remains the cornerstone for surgical education. Lyon (2004) reported that 'operation theatre provides a sensory perceptual experience' to help students develop a 'clinical memory' of the procedure. Students get to observe the involved pathology, touch and understand its spatial location and visualise the surgery at a greater detail. However, restricted resident training hours severely affected teaching within the operation theatre (Kapralos et al. 2014; Royal college of surgeons 2014). The reduction in training hours also reduced the interaction between the trainer and the trainee affecting their teamwork and communication skills (Hartle et al. 2014). Further, less working hours has increased pressure on faculty to hike their productivity (AAMC 2010), negatively affecting the teaching within the operation theatre (Kapralos et al. 2014). A solution for this problem as suggested by Roberts et al. (2012) is for surgeons to identify alternative innovative methods of training.

## 8.2 Innovation in Surgical Training Methods

Efforts to find suitable adjunctive to conventional training methods led surgeons to use simulation, serious games and virtual reality for training novice surgeons, just like flight simulators for pilots (Jackson and Gibbin 2006). The following is a brief review of advances in surgical training methods.

### *8.2.1 Surgical Simulation*

Simulation provides surgeons with a safe and repeatable environment for practising their skills without causing any damage to the patient (Issenberg et al. 1999). Multiple studies (Evgeniou and Loizou 2012; Kapralos et al. 2014) have confirmed the positive implications of virtual reality and simulation for surgical training purposes including skill transfer (Sturm et al. 2008) and improvement in training efficiency (Gurusamy et al. 2008). They also help in shortening the learning curve of surgeons (Patel et al. 2006). Based on the technology used and the complexity of skills trained, the classification of simulators was made by researchers (Torkington et al. 2000). Simulators used in surgical training varied from physical simulators to computer-based virtual reality simulators (Sutherland et al. 2006). Physical simulators include cadavers, animal models and inanimate plastic models, foam suturing pads and box trainers for laparoscopic surgeons (Huynh-Thu et al. 2011; Vitish-Sharma et al. 2011). However, while physical models suffered from a lack of realism, cadaveric dissections suffered from a lack of their availability, legal restrictions and ethical concerns limiting their usage. These factors pushed researchers more towards technology-based surgical simulations including serious games and virtual reality experiences (Sarker and Patel 2007). Moreover, virtual reality-based simulators were found to be more effective in training surgeons than physical simulators (Orzech et al. 2012). However, lack of out of hour's access and reduced availability to trainees in the first 3 years of surgical training also highlight a major need to be met in developing future surgical simulators. In addition to these challenges, the high cost of production and investment in developing realistic surgical simulations prevents a worldwide acceptance of these simulators.

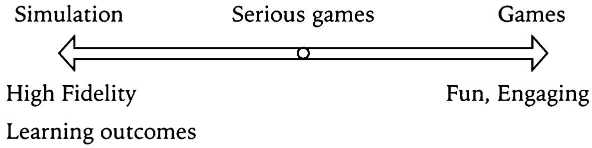


**Fig. 8.1** Differences between simulations and games (Graafland et al. 2012)

### 8.2.2 *Serious Games for Surgical Training*

Unlike simulations and games, serious games provide measurable learning outcomes in a fun and engaging manner (Graafland et al. 2012) as shown in Fig. 8.1. A detailed systemic review on the application of serious games in surgical training by Graafland et al. (2012) showed the gamification of surgical education for decision-making, teamwork and cognition. Issenberg et al. (2005) detailed the essential aspects of simulations which can improve learning in medicine are feedback, ability to practice repeatedly and introduction into the curriculum. Serious games with competitive elements including challenge-driven practice and incentives-driven scoring techniques were found to play a major role in surgical training (de Wit-Zuurendonk and Oei 2011).

Challenge-driven serious games can be applied where repeated practice is necessary to gain expertise, such as decision-making skills. Intraoperative decision-making, one of the essential skills for surgical trainees, can be learned through this technique (Michael and Chen 2005) as serious games provide an opportunity for deliberate practice till a level of expertise is reached. Another application of gaming element for decision-making is seen in a mobile app, Touch Surgery (Surgery 2015). This application trains the cognitive skills of surgeons through cognitive task analysis method (Wingfield et al. 2014) and tests decision-making skills. In addition to the above-mentioned aspects, feedback in learning, intrinsic scoring and multiplayer performance in serious games help the trainees to practice their teamwork skills. When such serious games are applied in a clinical environment (Kneebone 2009), they will reinforce the communication and teamwork skills necessary to practice in real-life emergencies. However, serious games suffered from a lack of fidelity, high investment involved and low immersion of users when not displayed on virtual reality devices.

### 8.2.3 *Immersive Virtual Reality in Surgical Training*

Immersive virtual reality experiences provide a sense of 'presence' to the user. They require the user to wear a head-mounted display or goggles to engage visual senses, headphones to engage auditory senses and occasionally gloves to engage tactile sense. The first immersive experience was created using a mechanical device called the Sensorama. Rapid advances in technology and research led to the introduction of commercially available high-quality immersive virtual reality devices including Oculus Rift (Te 2015), HTC Vive (2015), Gear VR (Samsung 2015) and Google Cardboard (Google 2015). Amongst these devices, Gear VR and Google Cardboard create a portable virtual reality environment as they work with smartphones.

Applications of Oculus Rift in medical education started with anatomy applications (Carson 2015), whereas their role in surgical education began with MOVEO Foundation (Rousseau 2014). The first immersive surgical experience was recorded using a head-mounted Dual Hero GoPro camera rig to provide a first-person perspective of the surgical process. Immersive technologies are ideal for surgeons to experience real-life scenarios, which are not faced frequently in their regular practice (Moorthy et al. 2006). A realistic simulation of operating room on these devices can cut down the costs spent in training surgeons (Bridges and Diamond, ASIT 2015). Oculus Rift-based experiences create the possibility of situated learning (Lave and Wenger 1991) and support the idea of contextualised learning (Kneebone et al. 2004; Kneebone 2009), where surgeons can learn within a clinical environment, such as operating room Paige et al. (2009). Recently, a 360-degree experience of surgery on a head-mounted display was demonstrated by a UK-based colorectal surgeon, Shafi (Quinn 2016), where a surgery to resect cancer was viewed by trainees all over the world. Applications like these show how global inequalities in surgical training can be solved with virtual reality. However, the existing and developing VR surgical training applications suggest the need for more evidence on their impact on surgical training, which the VR Surgery project is aiming to provide.

## 8.3 VR Surgery

VR Surgery provides an immersive learning experience for surgical trainees through pre-recorded stereoscopic 3D videos of surgery and interactive models of patient's anatomy using an Oculus Rift headset. The surgical procedure demonstrated in this application is Le Fort 1 surgery, a type of maxillofacial surgery, performed to correct lower midface deformities (Miloro et al. 2004). This section discusses the equipment used and the design of VR Surgery application.

### *8.3.1 Hardware and Software*

*Oculus Rift* head-mounted display is selected due to its availability, cost and efficiency at the time of research. It is also compatible with motion tracking devices such as Leap Motion and Unity3D game engine, which allow development of VR applications. Additionally, strong online support communities of Oculus Rift were useful in building this app.

**Fig. 8.2** Six GoPro cameras in freedom 360 setup (Go Pro 2014)

*Leap Motion* is a motion tracking device which tracks the position of the bones in the hand. This device was chosen for its ubiquity in use, low cost and ease of use with Oculus Rift and Unity3D application. Moreover, it was only the hands that needed to be tracked for this application, and Leap Motion fulfilled the task appropriately.

*GoPro 360-degree cameras* were used to capture the operating room in 360 degrees as they are small in size, can capture 1080pHD videos and render an easy to edit output. Six GoPro cameras were arranged in a setup as shown in Fig. 8.2 to record the entire operating room in 360 degrees.

*Sony 3D stereoscopic cameras* were chosen to record the surgery in a close-up stereoscopic manner due to their high quality, low cost and ease of availability.

Unity3D game engine is used to integrate all the components of the application and create a VR application on Oculus Rift due to its cross-platform compatibility and robust functionality. Other softwares used for building the application include Autodesk 123D for 3D scanning, Autodesk Maya for modelling and animation, GarageBand for editing audio and iMovie, Final Cut Pro, Adobe After Effects, Adobe Premiere, GoPro video manager and AutoStitch for editing video and post-production.

## *8.3.2 Design of VR Surgery*

The immersive experience in VR Surgery was designed following multiple steps as shown in Fig. 8.3.

We discuss three components of VR Surgery design elements, i.e. content design, application design and user feedback.

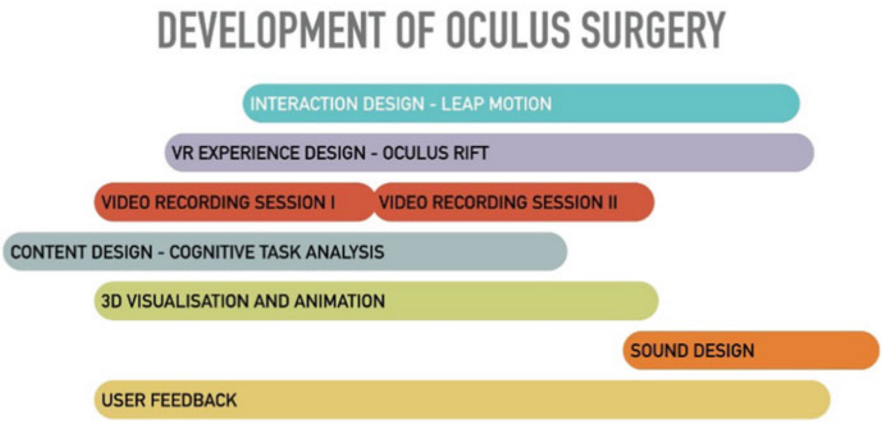


**Fig. 8.3** Design elements of VR Surgery

#### 8.3.2.1 Content Design

Maxillofacial surgery involves the surgical procedures of the face and jaws. Orthognathic surgery is one of the types of jaw surgery, which is very complex in nature involving the movement of jaws to correct facial deformities. Due to the level of complexity and lack of innovative training tools, Le Fort procedure (Miloro et al. 2004), a form of orthognathic surgery, was chosen for VR Surgery. Le Fort 1 procedure or horizontal maxillary osteotomy involves the fracture line or osteotomy at the base of the upper jaw above the tooth apices. The surgery was divided into a sequence of logical steps, following cognitive task analysis technique. Cognitive task analysis (CTA) creates a logical sequence of knowledge so that decision-making and other cognitive skills can be learned in a structured approach (Li 2005). Multimedia methods applying cognitive task analysis were found to enhance learning (Luker et al. 2008; Clark et al. 2012; Wingfield et al. 2014). Based on these findings, we split the content in VR Surgery into four steps:

1. Preoperative preparation
2. Soft tissue incision and exposure
3. Bone cuts, disimpaction and mobilisation
4. Bone fixation and suturing

#### 8.3.2.2 Application Design

The application was designed to work in a *see one, simulate* one *and teach one* approach for surgical trainees (Vozenilek et al. 2004). Out of all the three, more focus was laid on the visual experience as it plays a major role in providing a sense of immersion (Huynh-Thu et al. 2011).

**Fig. 8.4** Surgical environment for Le Fort 1 surgery

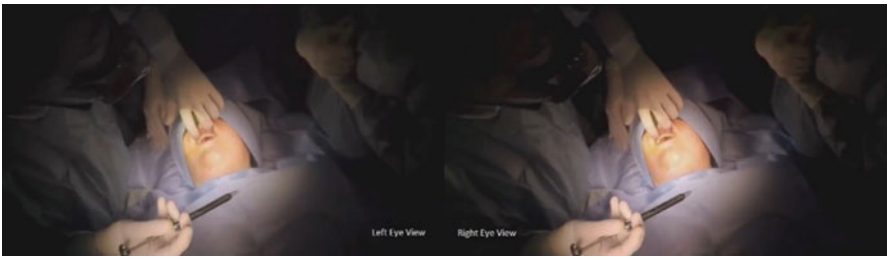


**Fig. 8.5** 3D video of operating room

## See One

Understanding an intricate surgical procedure by watching it over a surgeon's shoulder in a crowded operating room is a challenge (Reid 2007). During maxillofacial surgery procedures, it gets even more challenging to the trainees as there are always up to four hands covering the patient's face as shown in Fig. 8.4. A stereoscopic 3D video was used as shown in Fig. 8.5 to provide a detailed view of the surgical process. This 3D video provides depth perception and realistic view of the surgical procedure (Wagner et al. 2012). On the other hand, the context was found to play an equally important part in addressing the level of immersion (Kneebone et al. 2004). When the context of simulation closely resembles a real-life model, such as an operating room environment, learning was found to be better. To create such an experience, 360-degree video of operating room was introduced in the application.

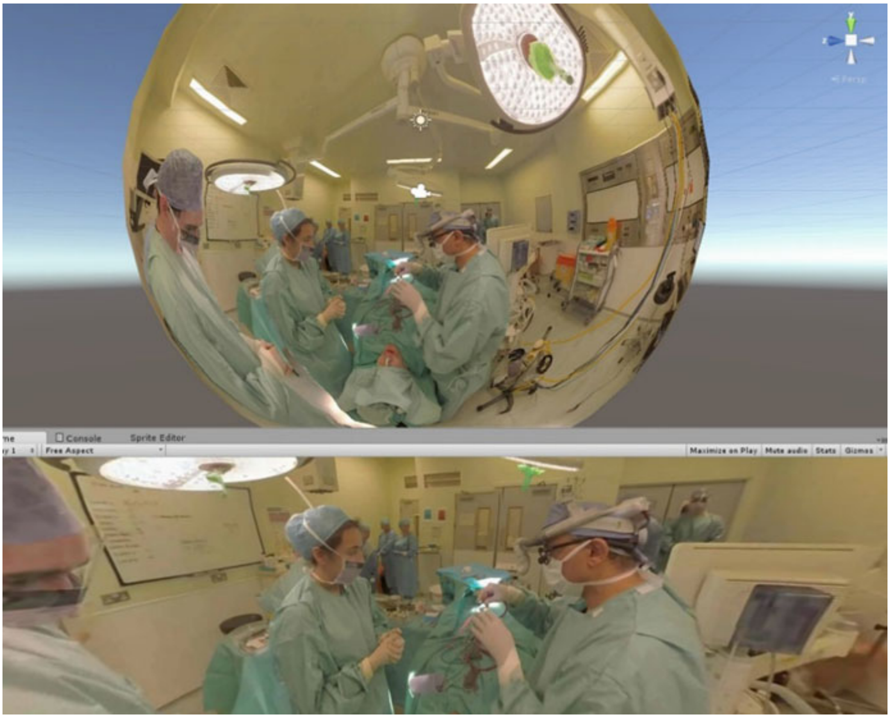


**Fig. 8.6** 360-degree video of operating room

Six GoPro cameras were used along with a Hero 360-degree setup as discussed earlier. A consultant VR specialist collaborated with our team to capture the surgery in 360 degrees and 3D stereoscopic views (Miller 2015). Individual camera settings and white balance were standardised to run the cameras in unison. To enable error-free video stitching at later stages, motion synchronisation (Kolor 2015) of the cameras was done by rotating the rig to and fro. Natural challenges of sterility, blood-filled field and distance from the surgical field inherent in every video recording within an operating room environment Pallace (2014) were negotiated by proper positioning of the cameras. The resultant 360-degree video was placed on the inner walls of a sphere to provide the user with the context of operating room as shown in Fig. 8.6.

Simulate One

To be able to touch and interact with objects in the application fulfils the second essential element of VR experience interactivity. Leap Motion device is used to establish interactivity in the app by attaching it to the Oculus Rift (Leap 2015). The

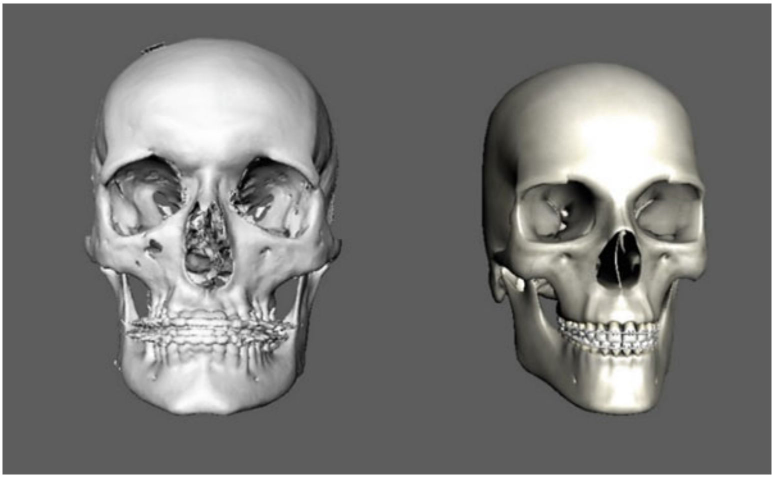

**Fig. 8.7** 3D surface model generated from CT scanned data (*left*) and 3D model of skull modelled in Autodesk Maya (*right*)

user can place his hand in front of the Oculus and touch to interact with the objects in the virtual world. 3D CT scan data and dental casts were scanned and modelled using 123D Catch and Autodesk Maya to show the pre-surgical plan as in Fig. 8.7. Interactive models of skull anatomy and animations of surgery were used for tasks and questions. The users can zoom in and touch the annotated 3D models of the skull while also isolating one or a group of structures to inspect anatomic relationship between them. The trainees can also control the animations of the surgical process while interacting with the model. As the platform was designed to work with an integrated Oculus-Leap Motion, the best practices in interface design are followed for a satisfactory user experience design (Leap Motion 2015).

### Teach One

The third aspect of this application is the element of teaching. VR Surgery follows the Kolb's learning model in providing an appropriate learning experience for the surgical trainees as shown in Fig. 8.8 (Kolb et al. 2001).

Knowledge about the surgical procedure, pre-surgical plan, instruments and relevant anatomy were presented in the form of 3D videos and interactions. These represent the concrete experience aspect. A feedback on performance through questions and tasks helps trainees to reflect on their knowledge. This reflective observance is guided through scores and notifications. Abstract conceptualization aspect is represented by the steps to improve the performance of trainees, such as revising their knowledge regarding anatomy and instruments by interacting with the

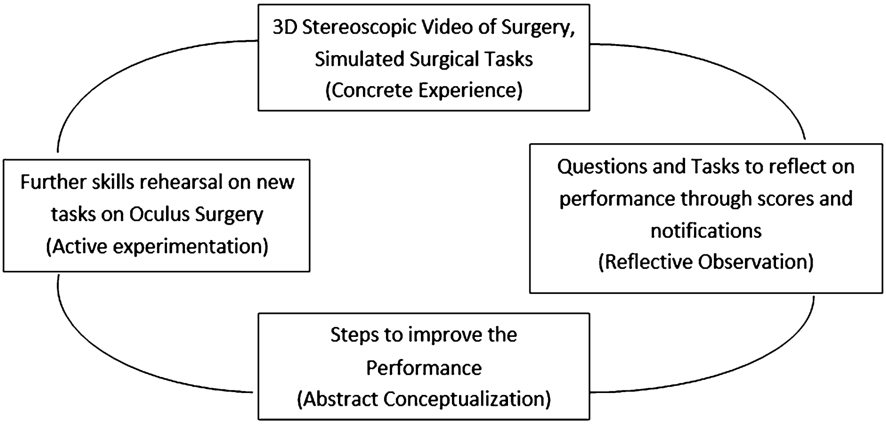


**Fig. 8.8** The *teach one* approach in VR Surgery

3D models. Following this, a trainee can return to the application and answer a set of new questions and take up the tasks regarding the surgical procedure, representing active experimentation phase.

A summary of key features in various scenes of VR Surgery and the purpose behind their use is shown in Table 8.1.

#### 8.3.2.3 User Feedback

Throughout the application design, feedback on usability, design and content were gathered from surgical trainees in maxillofacial surgery, supervisors and colleagues. This helped the system to be robust and comfortable for usage, especially in viewing content in 3D and in designing Leap Motion-based interactions. An image of the users testing VR Surgery can be seen in Fig. 8.9.

## 8.4 Discussion

Surgical education needs major reforms to face emerging challenges including reduced training hours and decreasing number of surgical faculty. Simulation promises to be adjunctive to existing training methods. However, high costs, lack of access and limited availability of high-end simulators prevent trainees from taking full advantage of these systems. The introduction of Oculus Rift- and HTC Vive-like devices brought high-quality surgical simulations into common man's reach with some barriers to cross. These head-mounted VR devices require high specification software and hardware for a satisfactory virtual reality experience (VR 2016). However, high specification computers are not easily available in university teaching

**Table 8.1** Scene design of the VR Surgery

| Scene | Purpose |
|---|---|
| 1. 3D stereoscopic video | Orthognathic surgery involves the movement of the bones in a 3D space. As 3D stereoscopic videos enhance the depth perception, they were chosen over conventional 2D videos. These videos allow surgical trainees to watch the procedures in great detail |
| 2. 3D interactions | 3D interactions help the user in understanding the surgical procedure from different perspectives. This involves: |
| | 1. 3D animations of the surgery |
| | 2. 3D anatomy |
| | 3. Interaction with instruments |
| | 4. Interaction with patient's data |
| 3. 360-degree video of surgery | Operating room environment, the sounds and teamwork are essential cues in surgical training. To create a realistic learning environment and to create a sense of 'presence', 360-degree videos were used |
| 4. Virtual operating room | During training, there are various elements other than the surgery itself, including 3D data, surgical instruments, negotiating the terms of the operating room and understanding the interpersonal relations. The virtual operating room scene allows the user to walk around the operating room environment and experience the ambiance |
| 5. Quiz | While watching a surgical procedure, trainees are asked questions about the anatomy of the patient, surgical procedure, potential complications and instruments used. This helps them to connect various elements and reinforce the knowledge with the experience. Real-time feedback will improve their learning |
| 6. Instruments | Le Fort 1 surgery uses a wide variety of instruments. As surgical trainees need to know the instruments and their order of usage, this scene is a very useful learning tool |
| 7. Anatomy | Learning the surgical anatomy is an essential cognitive skill before any procedure. Users can touch and learn different aspects of skull anatomy. Scenes showing potential complications of orthognathic surgery are also introduced in VR Surgery |
| 8. Instructions | VR environments and devices like Oculus Rift need instructions to understand how different elements work in the application. This scene guides a trainee on: |
| | 1. How to walk/move in a 3D environment |
| | 2. How to interact with instruments |
| | 3. How to interact with various elements in the quiz scene |
| 9. Pre-surgical planning | Before the surgical procedure, understanding why the surgery needs to be done using the CT scan data of the patient is essential. This scene allows the trainees to interact with the patient's CT scan data and also dental scans |

hospitals and NHS (Serjeant 2016). In addition to that, an investment in VR hardware such as Oculus Rift or HTC Vive pushes the users to look into cheaper solutions of experiencing immersive VR, e.g. Google Cardboard (Google 2015). Despite all the advances, a lack of awareness of innovative VR technologies can be the reason for the trainees to not experience this mode of training. But once


**Fig. 8.9** Users interacting with VR Surgery

the challenges are met, VR Surgery like applications provide an alternative way of learning and can reduce the time taken in training surgeons in operating rooms (Vinden et al. 2016). The future work of the VR Surgery project is to validate and evaluate its impact on training surgeons through rigorous validity experiments. Until then, immersive VR simulations can only be adjunctive methods of training, not a substitute of conventional training as suggested by Sutherland, Middleton et al. (Sutherland et al. 2006).

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# Chapter 9
# Creation of E-Tutorials to Enhance Medical Student Anatomy Learning Experience Using Articulate Storyline 2

**Paul Rea and Aileen Linn**

**Abstract** With technological advances and accessibility continually improving, it is becoming increasingly relevant to incorporate this in education. Increasingly, there has been a shift in self-directed learning with teaching methodologies incorporating both traditional means and online learning. With this in mind, we ran a Student Selected Component (SSC) for second year medical students where they would create their educational anatomical content using the software Articulate Storyline 2. Nine students completed this module, with three groups of three students creating individual anatomical packages. Using interactive videos, images, Anatomy.TV, photogrammetry, text and cartoon characters, these students created anatomy packages for cardiovascular, gastrointestinal and hand and wrist anatomy. During the SSC process, the students were required to complete initial alpha testing of the e-tutorials within their SSC group. Students from the MBChB programme were invited to partake in the beta evaluation studies to assess the effectiveness of the content created. The students who participated in the SSC benefitted from the process of being active participants and cocreators of their learning experience while producing extremely useful educational resource for their peers. This type of approach to educational resource development, created by the student for the student, is recommended as a policy to adopt on a wider basis, not just for medical students but the wider higher education sector.

**Keywords** Anatomy • Anatomy education • Articulate Storyline 2 • E-Tutorial • Medical education

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## 9.1 Introduction

Anatomy, derived literally from the Greek *anatom*e, is a word built up from *ana*, literally meaning up, and *tome*, meaning cutting. The science of the structure of the body has had such a rich and florid history throughout the ages. From its origin in Egyptian times, and the writing of the first ever surgical text called the Edwin Smith Papyrus (https://ceb.nlm.nih.gov/proj/ttp/flash/smith/smith.html), anatomy has had made significant scientific advances with some key contributors like Aristotle, Herophilos, Galen, Vesalius and Da Vinci. Indeed, anatomy has also had some scandals in its time, but is now heavily regulated in its legal practice (http://www.legislation.gov.uk/ukpga/1984/14/contents; http://www.legislation.gov.uk/asp/2006/4/contents).

Nowadays, anatomy is one of the cornerstones of a medical education, with cadaveric dissection featuring as one of the key teaching methods. However, not all universities offer dissection for several reasons including the cost, the infection risk (e.g. prions) and the risk to technical staff like embalmers, from handling the fluids (de Craemer 1994; Miller 1988).

Anatomical training and its place in the medical curriculum was significantly reduced some years ago (Patel and Moxham 2008). At that time, and since, concern has been raised over this reduction of anatomical training and 3D competence of medical graduates (Turney 2007). The main issue was in relation to the future doctors having anatomical knowledge and understanding safe for clinical practice. Then into 2009, Tomorrow's Doctors stated there should be more focus on the underlying "basic" sciences and that technological advances should be embraced (Tomorrow's Doctors 2009).

Ever since Professor Robert A. Chase, based on the University of Stanford in the 1970s, created a digital representation of a sectioned female pelvis, there has been considerable advancement in the tools available to be able to embrace the technological advance for anatomical and medical training. The first comprehensive attempt of the creation of a full digital training resource for anatomy came from the cross-sectional Visible Human Project (VHP) (Spitzer and Whitlock 1998). It was created in 1989 at the University of Colorado and is, to this today, revolutionary in the creation of the digital cadaver. It was based on two bequeathed donors who were CT and MRI scanned, with cryosections at regular intervals taken to build the fully interactive digital model.

Since that point, and with the explosion of access to information on the Internet, there has been an abundance of products, which have been created to try to aid anatomical understanding for medical, dental, nursing and allied health professionals. Some of the better known to the market include the Visible Body (Visible Body 2016; ZygoteBody 2016; 3D4Medical 2016) and, one of the most popular on the current market, that of Anatomy.TV offered by Primal Pictures (Anatomy.TV 2016).

One of the issues that products on the market have is that there is considerable variation in the content, level of detail and features of interactivity. Indeed, none of these products will be created with a specific course in mind, and each course and institution will have different learning requirements and objectives that must be met during the learning process. However, this increase in digital products for higher education means that using and applying technology for teaching and learning can actually be engaging not only for staff but also for the students themselves. In 2002, Davis discussed that for students to learn, they must do much more than simply listen, as this process requires student engagement and active participation in that process (Davis and Sumara 2002). It is crucial, though, that to allow a transformative approach to instructional design, technology must be able to address the need to enhance student learning but also support them during this process (McCulloch 2009).

Medical degree programmes in the UK have an element of choice where the student can personalise their learning experience at medical school. The current document related to education and training of medical students states that they should be given “the opportunity to choose areas they are interested in studying while demonstrating the learning outcomes required for graduates” (http://www.gmc-uk.org/education/27394.asp). As such, and for the first time at a local level at the University of Glasgow, UK, we developed a specific Student Selected Component (SSC) entitled “Development of Anatomy E-Tutorials” to be offered to students in their second year of the undergraduate medical degree (MBChB). The aim of this SSC was to allow students to become active participants and cocreators of their own e-tutorials, using Articulate Storyline 2 software, and, thus, develop their own learning experience. A senior clinical anatomist (PR) and an e-learning development officer/university teacher (AL) supervised it. As part of the SSC, students were required to complete initial alpha testing within their SSC group, before inviting their colleagues on the MBChB programme to assess and review the e-tutorials completed at the beta evaluation stage. This ensured that the digital products being created were assessed and reviewed by their peers, as the purpose of this SSC was to create resources by students and for students and to work in partnership with the students to meet their needs.

This SSC project was offered for a maximum of nine students and all places were filled. The students were divided into three equal groups. The commencement of the SSC was based around reflection of areas that were challenging anatomically or needed further resources developed, in addition to the current teaching they received. The remit was to develop three unique and individual packages using the software Articulate Storyline 2, which would benefit not just the students undertaking the SSC but the wider community of medical students. Articulate Storyline 2 was selected for the development and creation of anatomical resources due to its likeness to PowerPoint and relative ease of use and substantial online support resources. Images, videos, quizzes and interactive resources can easily be embedded into the templates for the creation of an e-tutorial with a variety of formats and layouts, with the tool of being able to embed cartoon characters to engage the learner, making it fun and visually stimulating. After initial training in the use of this software package, the groups identified the areas of challenging anatomy they felt required additional resources to be made available to their colleagues, namely, in cardiovascular, gastrointestinal and hand and wrist anatomy.

The initial phase of the SSC involved the students working within their groups to storyboard their ideas, sketching out concepts and discussing the interactivity they could build into their e-tutorials. Once this was extensively covered, student proceeded with the initial developments of the e-tutorial for the first 2 weeks of the project. At this stage of the process, the students were gaining confidence in their e-tutorial development, and the first stage of end-user evaluation (alpha testing) was introduced to give a practical insight into how the e-tutorial is approached and any potential technical barriers that may be encountered by the end user. This is an integral part of the e-tutorial development process. The overall requirement is to test the efficacy of the product design, interface, content and its accessibility, particularly taking into account the known attributes of the target audience (undergraduate medical students).

The aim of the alpha review was to identify any discrepancies between the storyboard and the tutorial as it appeared on the screen. Until the tutorial is viewed on screen, it is difficult to see all the content as an integrated learning experience. All of the students in the SSC group took on the role of reviewers checking the e-tutorials produced by their colleague groups, to ensure that the appropriate level of content has been included, if any content was superfluous, missing or unclear and to identify usability issues. The students were involved in planning the alpha usability testing stage and discussed the most appropriate moderating technique, the concurrent thinking aloud model, that was deemed most appropriate, and all students participated in the reviewer and reviewed role.

Following the alpha review, the students met to discuss the evaluations and to focus on which changes they would like to incorporate into the e-tutorial and justified those they chose not to include. They found this stage of the design and development an incredibly useful part of the process, to enable them to review their e-tutorials through the eyes of their colleagues, and significantly impacted on the design and further development of their e-tutorials.

The second stage of the usability testing completed was the beta testing phase, and students on the SSC project designed a pre- and post-evaluation questionnaire with the intention of obtaining feedback from colleagues on the MBChB programme on the value of the e-tutorials.

The following questionnaire was used to assess the effectiveness of the e-tutorial; the pre-evaluation questionnaire focused on student's attitudes to the effectiveness of e-tutorials and online resources and their confidence in the particular region of anatomy. The post-evaluation questionnaire focused on the value of the e-tutorial developed. A list of the questions used, valid for all tutorials and student users, is highlighted in Table 9.1.

**Table 9.1** This table details the questions asked pre- and post-evaluation of the student participants during beta evaluation of the e-tutorials created in Articulate Storyline 2

| Pre-evaluation questions | Post-evaluation questions |
|---|---|
| What is your registration number? | What is your registration number? |
| What year group are you in? | Which tutorial did you evaluate? |
| Are you male/female? | Please state any technical difficulties (if any) you experienced accessing the e-tutorials |
| What age are you? | Having completed the e-tutorial: Think about your level of confidence in your knowledge of this topic. Indicate the degree of confidence using the following (10-point) scale |
| Have you done another degree? | Using this e-tutorial has increased my knowledge of anatomy (5-point scale) |
| 10-point confidence scale. Think about your level of confidence in your knowledge of the Anatomy of the Heart. Indicate the degree of confidence you have in your knowledge using the following scale | Using this e-tutorial has highlighted gaps in my knowledge (5-point scale) |
| Have you ever used an e-resource to study before? | Using the e-tutorial filled the gaps in my knowledge (5-point scale) |
| If yes please specify which of the following you have used | Using the tutorial was a valuable use of my time (5-point scale) |
| Do you think that e-resources are an effective way to learn? | Using the e-tutorial was more effective than paper-based resources (5-point scale) |
| If no what reason would you give? | Using the e-tutorial was enjoyable (5-point scale) |
| Which devices do you use for study? Please tick all that apply | The e-tutorial was easy to navigate (5-point scale) |
| | I would recommend the e-tutorial to a friend (5-point scale) |
| | I would use e-tutorials more often if they were available in other topics (5-point scale) |
| | Having access to the e-tutorial will add value to the course (5-point scale) |
| | I would use the e-tutorial again (5-point scale) |
| | When would you like to have access to the e-tutorial? |
| | What changes would you make to the e-tutorial? |
| | What positives did you find with the e-tutorial? |

## 9.2 Anatomy of the Heart E-Tutorial

This group identified the need for images of real anatomical specimens to be embedded into the tutorial, with interactive content as a useful learning tool. As such, they identified several heart specimens that were the type used in teaching sessions, which were selected from the regular stock in the Laboratory of Human Anatomy (LHA). Permission for images was granted by the donors of these cardiac specimens, and the body donation programme is regulated under the Anatomy Act 1984 and the Human Tissue (Scotland) Act 2006. This group, like the others, used Articulate Storyline 2 for the creation of the e-tutorials. However, for a section within the tutorial, they performed photogrammetry on some anatomical specimens from the LHA. Using Unity, this provided an alternative viewing platform within the tutorial to examine anatomical specimens in an interactive format. This student group used advanced imaging by means of photogrammetry using the following equipment and software:

1. Canon 650D and 700D digital camera to capture anatomy specimens for photogrammetry.
2. 123D Catch v3.0 for the 3D generation initial. This is Autodesk software and is free for non-commercial use.
3. Unity v4.6.2 was used for creating the viewing environment.
4. Unity web player for viewing the 3D material.

In addition to this, the group also wanted to embed histology images, and as such they digitally captured four types of histological sections, namely, cardiac muscle (haematoxylin and eosin), aorta (haematoxylin and eosin), sinoatrial node (Masson's trichrome) and cardiac muscle using Masson's trichrome. These sections were chosen from the regular histological collection in the LHA. The slides were digitally captured using an Axiosoft 2 microscope with an attached AxioCam MRc camera. These images were digitally processed using the Axial Vision version 4.8 software.

This group also created their own anatomical drawings from lectures of heart anatomy and related structures. In addition, images from Anatomy.TV (a software package that the University of Glasgow subscribes to) were also embedded into the tutorial. These images could be used and published in agreement with the Copyright and Rights in Performances Regulations 2014.

### *9.2.1 Results of Cardiovascular E-Tutorial*

This student cohort created a comprehensive package on cardiac anatomy. From the home page, there was the option for viewing the acknowledgement section and also a brief overview of "How to use the tutorial". The main clickable button was the "Start" option from the home page. This group offered users the opportunity to a "Pick a Topic" in cardiac anatomy with ten options of:

(a) Regional anatomy
(b) Layers of heart wall
(c) Cardiac muscle
(d) Chambers, valves and blood flow
(e) Innervation and nodes

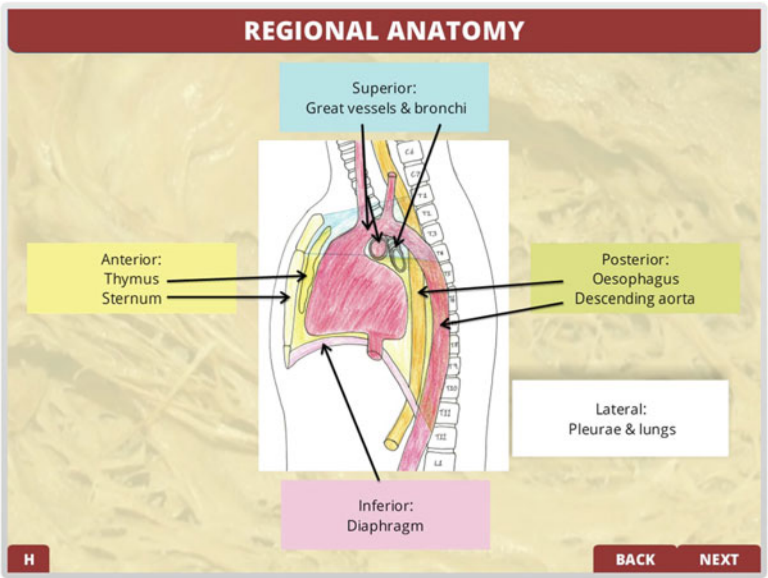


**Fig. 9.1** Image of the diagrams used to highlight cardiac anatomy

(f) Vasculature
(g) Thoracic aorta branches
(h) Surface anatomy
(i) Cardiac imaging and a final section entitled Total Quiz Results

#### 9.2.1.1 Regional Anatomy

This section allowed for an overview of the simplistic anatomy of the thoracic cavity, presented in picture format using representative images, drawings and a simple quiz in the format of true/false, multiple-choice questions and text box answers (Fig. 9.1). Instant feedback for the user was given on their performance in answering the questions.

#### 9.2.1.2 Layers of Heart Wall

This brief section was based on a line drawing of the heart, with some simple explanations of the terminology used to describe the various layers. It was followed by a quiz using multiple-choice questions and a drag-and-drop section and text box questions.

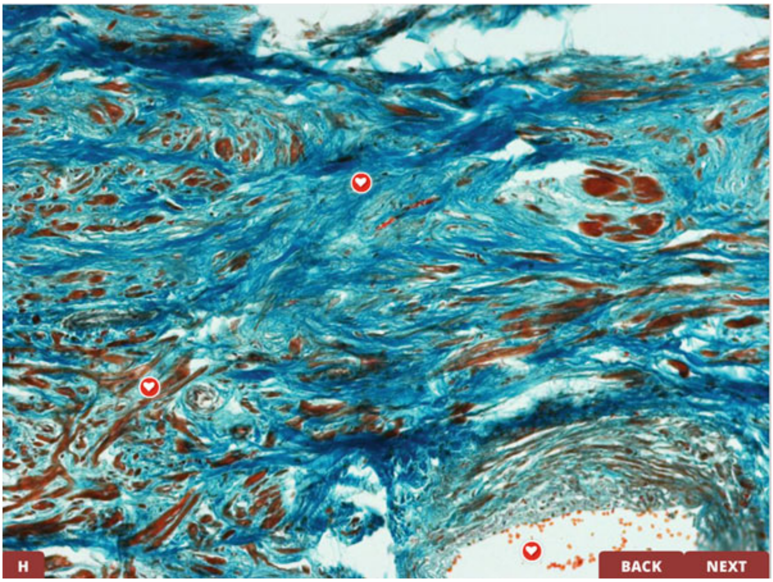


**Fig. 9.2** Sinoatrial node, Masson's trichrome. Note the heart symbols, which, if the user hovers over, provide more detailed explanation of histological structures. There is a home button (H) and a back and next button to progress through the tutorial

#### 9.2.1.3 Cardiac Muscle

This section incorporated the images captured from histological section from the LHA, with further information given via heart symbols as shown in Fig. 9.2.

#### 9.2.1.4 Chambers, Valves and Blood Flow

Images of the prosections from the LHA were utilised for this section with a Unity web player for viewing the photogrammetry of some of the actual human specimens, as shown in Fig. 9.3.

#### 9.2.1.5 Innervation and Nodes

The innervation of the heart was presented with drawings produced by the students, including the conduction system. Again, a quiz completed this section for user testing of their knowledge acquisition.

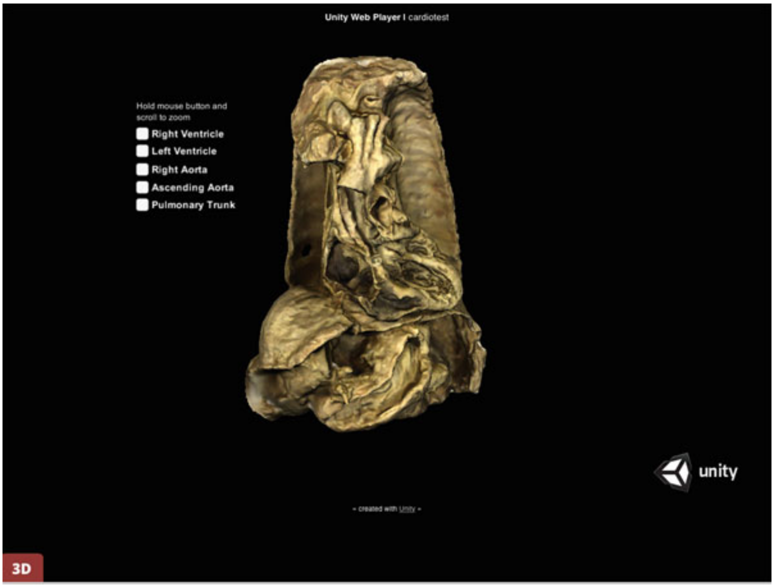


**Fig. 9.3** Unity image of photogrammetry of the prosected anatomical specimen, with interactive questions

#### 9.2.1.6 Vasculature

Images from Anatomy.TV were used for this section, and more text descriptions were made available to the user, with a quiz completing this section.

#### 9.2.1.7 Thoracic Aorta Branches

This section used simple coloured line diagrams of the aorta and the major vessels arising from it.

#### 9.2.1.8 Surface Anatomy

This section highlighted the clinical points of a chest examination and where specifically to listen for heart sounds, including a mnemonic to aid the end user in remembering heart murmurs, and when they occur in the cardiac cycle.

#### 9.2.1.9 Cardiac Imaging

This section provided extensive detail on the types of investigative tools used clinically including PET scans, MRI, Doppler, ultrasound and coronary angiography. It also discussed the details of how the procedures were carried out and any risks associated with each of them.

#### 9.2.1.10 Total Quiz Results

The final section detailed how the user of the quizzes faired overall, as a mark out of 62. It provided global feedback over all quizzes, with local feedback given at the end of each section based on performance for the individual quizzes.

## 9.3 Attainment in Anatomy: The Abdomen

This group created their e-tutorial in a very different way to the previous section on cardiac anatomy. This group of three students incorporated images from Shutterstock or from Elsevier e-books, in accordance with the Copyright and Rights in Performance Regulations 2014.

### *9.3.1 Results of Attainment in Anatomy: The Abdomen*

From the home page, there were two options created for “Contact Us” and a list of resources used in the creation of the e-tutorial for the user to access. The main option on the home screen was the “Start” button. Clicking through to start the tutorial, this student group created four options based on broad anatomical terminologies routinely used in practice. The options provided to the end user were (a) Teach yourself anatomy, (b) Teach yourself histology, (c) Teach yourself imaging and (d) Test yourself section.

#### 9.3.1.1 Teach Yourself Anatomy

This section starts with surface anatomy, and by hovering the mouse over each of the nine regions of the abdomen, users can discover what organs lay in each territory. Following on from this, a brief description is given on the muscles of the abdomen followed by a section which the user can then click on an organ to explore further the anatomy of that specific anatomical structure, as shown in Fig. 9.4.

In addition, there are comprehensive anatomical details provided in each section, with question mark icons, where the user can hover over the items for interesting

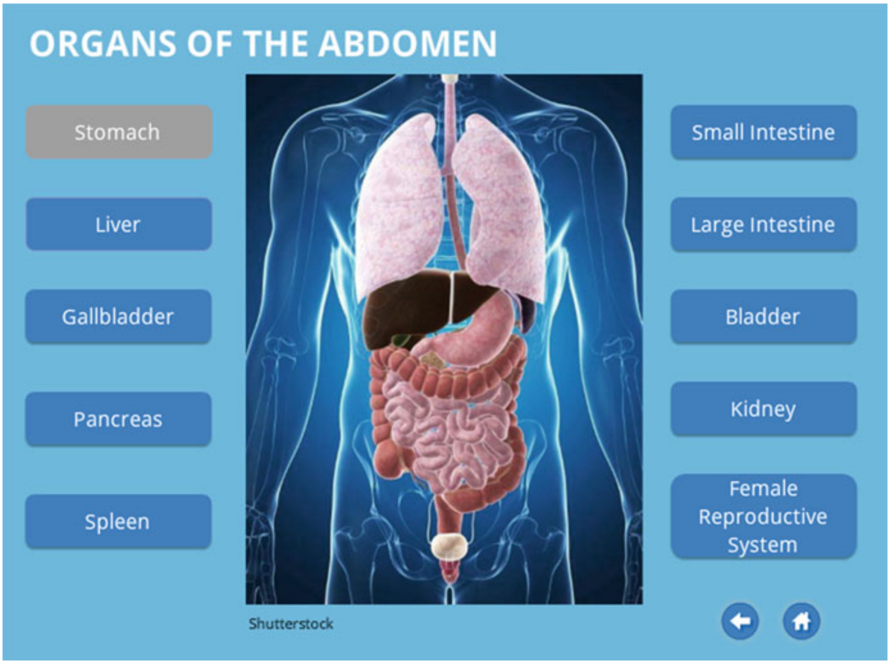


**Fig. 9.4** This shows the screen created for the student user to choose a specific organ to study. There is a home button and back option (Image source Sebastian Kaulitzki/Shutterstock.com)

facts. A stethoscope symbol was also adopted, generally down in the bottom left corner of the screen to highlight the clinical relevance of each part.

#### 9.3.1.2 Teach Yourself Histology

Four options were developed for the end user in this section, namely, GI tract, GI accessory organs, genitourinary system and female reproductive organs. A mixture of text, histological images and diagrams were incorporated into this section. In addition to this, and to make it directly relevant to the local taught curriculum, laboratory training material from the LHA was embedded into this component.

#### 9.3.1.3 Teach Yourself Imaging

This comprehensive section gave relevant clinical examples of CT, MRI scanning, X-ray and ultrasound imaging. In the CT and MRI sections, hovering over anatomical structures would highlight them and their anatomical boundaries.

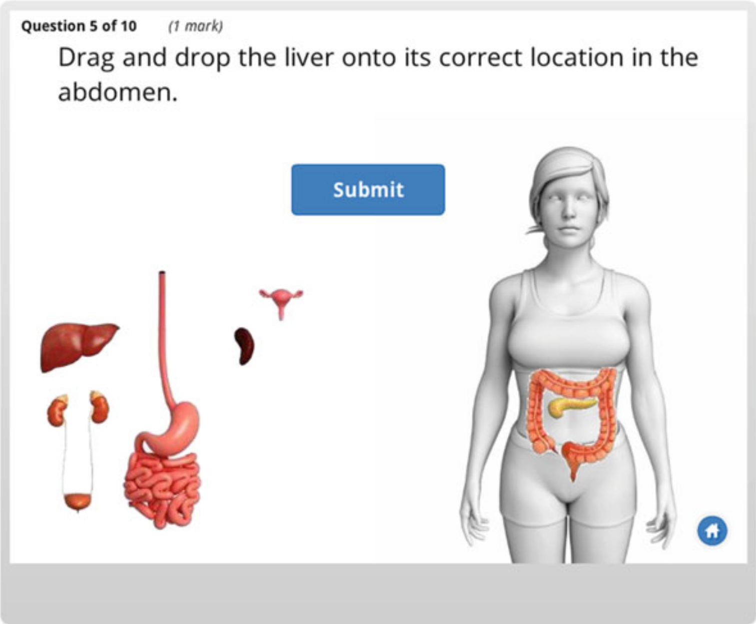


**Fig. 9.5** This shows a typical drag-and-drop option for placing organs onto the body. Only once fully completed can the user then submit for feedback on their answers (Image source S K Chavan/Shutterstock.com)

#### 9.3.1.4 Test Yourself

This section had three options of an easy, medium or hard quiz. It comprised of multiple-choice questions, lists of anatomical structures and drag-and-drop options where the student user would drag an organ onto a cartoon representation of the human body and identify if they were positioned correctly. This is shown in Fig. 9.5.

## 9.4 Anatomy of the Wrist and Hand E-Tutorial

This group used images from Anatomy.TV, a software package subscribed to, and widely used by, students of the University of Glasgow. All images were incorporated into the training package and made available for publication in accordance with the licence agreement. In addition, this group also incorporated images and videos of their own hand and wrist anatomy.

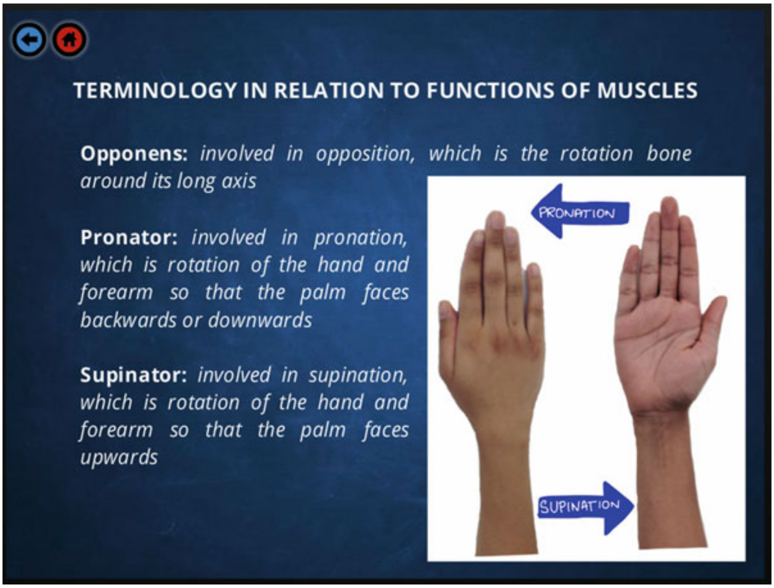


**Fig. 9.6** Image showing a student hand to demonstrate anatomical movements, with a text definition. There was a back button and a home icon to return to the main screen

## *9.4.1 Results of Anatomy of the Wrist and Hand E-Tutorial*

The final group of three students tackled this area of complex anatomy. Their package to be used by students comprised of a tutorial and a quiz section. In the tutorial section, the students created four main regions. These were introduction to terminology, gross anatomy, surface anatomy and clinical relevance sections. Cartoon characters were used to represent a virtual doctor giving the tutorial for visual engagement of the user.

### 9.4.1.1 Introduction to Terminology

This section discussed location, function, shape/size and positions as drop-down menus. For example, in the function section, images of the student's hands were used with illustrations to highlight key movements typical at the hand and wrist (Fig. 9.6).

### 9.4.1.2 Gross Anatomy

This comprehensive section had separate clickable options for bones, joints, ligaments, muscles and tendons, blood supply, anatomical snuffbox, carpal tunnel

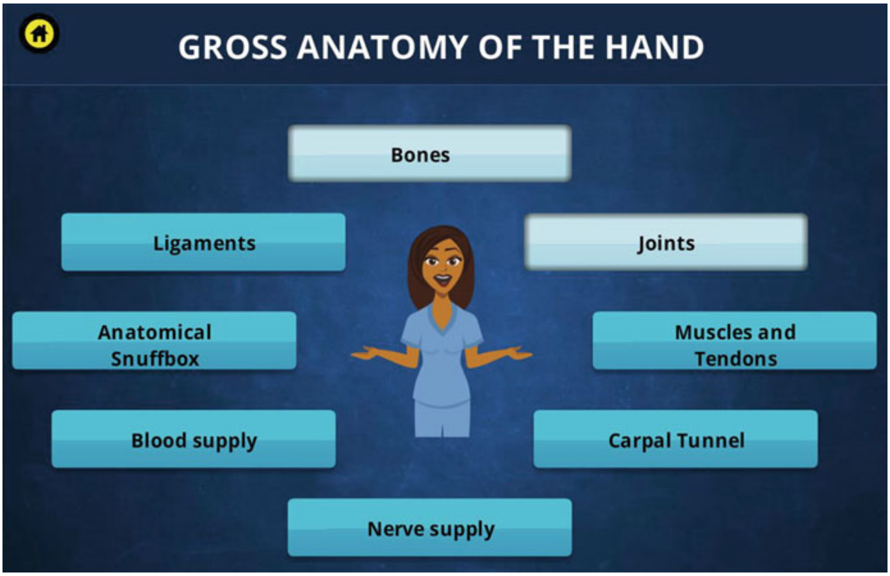


**Fig. 9.7** This image shows how the gross anatomy of the hand was presented and how it could be interrogated by the user. Clicking on each section provided more in-depth analysis of the anatomy of that region. Once the section was completed, the topic would change colour enabling easier navigation

and nerve supply as shown in Fig. 9.7. Most of these sections also had a self-test quiz section to enable the user to assess their knowledge and understanding and retention of it. Hovering over key areas provided further anatomical information and could lead onto underlying anatomy. There were information icons throughout that provided brief essential clinically relevant information.

#### 9.4.1.3 Surface Anatomy

This section had four options made available by the student creators for the user – inspection, palpation, movement and a quiz option. Annotated images were incorporated into this section and included surface anatomy landmarks.

#### 9.4.1.4 Clinical Relevance

Images were provided with interactive symbols where the user could hover over regions for more detail on clinical conditions affecting the hand and wrist. Specifically, the conditions examined in this section were ulnar claw, palmar erythema, nail clubbing and a quiz.

#### 9.4.1.5 Quiz

This section, accessed from the home page, included the same options for testing your knowledge as was addressed in the gross anatomy section, i.e. bones, joints, ligaments, muscles and tendons, blood supply, anatomical snuff box, carpal tunnel and nerve supply.

## 9.5 Results of Beta Phase End-User Evaluation

Beta phase end-user evaluation was completed using online questionnaires hosted on surveymonkey.com. All of the students on the MBChB programme were invited to participate in the e-tutorial evaluations.

### *9.5.1 Pre-evaluation Questionnaire*

In total 61 students participated in the beta evaluation study of the three e-tutorials. All students were required to complete the same pre-evaluation questionnaire (detailed in Table 9.1).

Students from all years of the programme participated in the evaluation, though the majority were mainly in the first 2 years of the programme as detailed in Table 9.2.

The majority of the 61 survey participants were female ($n = 39$), were under the age of 21 ($n = 41$) and had not completed a previous degree ($n = 46$). The vast majority of students already used e-resources to study (95%) and agreed that they were a useful way to study (95%). The most popular e-resources being used included YouTube (80%), recorded lectures (75%), PeerWise (75%), online quizzes (64%) and Anatomy.TV (62%).

Students used a variety of devices for study with a preference for mobile technology including laptops (93%), tablets (63%) and smart phones (63%) while still requiring access to a standard desktop computer (43%).

**Table 9.2** Student cohort distribution of research participants

| Student year group | Number of students |
|---|---|
| Year 1 | 32 |
| Year 2 | 19 |
| Year 3 | 4 |
| Year 4 | 4 |
| Year 5 | 1 |
| Intercalated | 1 |

### 9.5.2 Post-evaluation Questionnaire

To determine if the students felt their confidence in their knowledge of the topic of anatomy increased following the use of the e-tutorials, they were asked to rate their perceived confidence out of 100% on a 10-point scale before and after using the e-tutorial. Analysing the mean confidence scores for all participants' pre- and post-tutorial using unpaired t-test demonstrated a statistically significant increase in confidence ($P < 0.0005$) having used each of the three tutorials (results illustrated in Table 9.3).

The post-evaluation survey required the students to rate their agreement with a range of statements on a 5-point Likert scale (from strongly agree to strongly disagree). The results for each of the three e-tutorials are illustrated in Table 9.4.

The vast majority of students agreed or strongly agreed with the statement that the e-tutorial had increased their knowledge base of anatomy in the field (79–96% of responders).

Most student users of the e-tutorials also found that engaging with the software had highlighted areas where there were gaps in their knowledge, with 84–100%

**Table 9.3** Confidence level scores for research participant's pre- and post- completion of the e-tutorials

| E-tutorial evaluated | Pre-tutorial confidence mean (%) | Post-tutorial confidence mean (%) |
|---|---|---|
| Cardiology ($n = 28$) | 56.8 | 74.5 |
| Abdomen ($n = 22$) | 57.1 | 74.6 |
| Hand and wrist ($n = 19$) | 45.2 | 66.3 |

**Table 9.4** Percentage of students who strongly agree/agree with the post-evaluation questions

| Post-evaluation questions | Abdomen ($n = 22$) | Cardiology ($n = 28$) | Hand and wrist ($n = 19$) |
|---|---|---|---|
| Using this e-tutorial has increased my knowledge of anatomy | 87 | 96 | 79 |
| Using this e-tutorial has highlighted gaps in my knowledge | 91 | 100 | 84 |
| Using the e-tutorial filled the gaps in my knowledge | 87 | 86 | 89 |
| Using the e-tutorial was a valuable use of my time | 95 | 86 | 68 |
| Using the e-tutorial was more effective than paper-based resources | 64 | 61 | 58 |
| Using the e-tutorial was enjoyable | 87 | 79 | 58 |
| The e-tutorial was easy to navigate | 95 | 93 | 63 |
| I would recommend the e-tutorial to a friend | 77 | 86 | 79 |
| I would use the e-tutorials more often if they were available in other topics | 91 | 93 | 84 |
| Having access to the e-tutorials would add value to the course | 95 | 86 | 84 |
| I would use the e-tutorial again | 91 | 86 | 79 |

agreeing with this. There was variation between the responses for the e-tutorials with regard to the effective use of their time with 68% of users of the hand and wrist e-tutorial agreeing with this statement, while 95% of the abdomen e-tutorial users agreed. A similar variation in responses was also reflected in response to the question regarding ease of navigation and the enjoyment of using the e-tutorials clearly highlighting the importance of ease of use and quantity of information provided in these resources; an awareness of cognitive overload must be considered in the storyboard design.

While students valued these resources, only 58–64% agreed that they were more valuable than paper-based resources, indicating the ongoing value of textbooks, lab notes and lecture material for students.

Overall the vast majority of students would recommend using the e-tutorials to a friend. There was also a demand for further e-tutorials on a wider range of topics, as students felt they added value to their current medical degree programme. Most users would also use the e-tutorial again for revision and consolidation of their knowledge.

Students were also provided with the opportunity to provide free text comments to detail any changes they would make to the e-tutorials. Suggestions included adding more quiz questions including mini quizzes on each individual section and to include a large quiz at the end to consolidate knowledge; they also requested more feedback following an incorrect answer. Students would also like more details indicating which intended learning outcomes of the curriculum were covered by each section of the e-tutorial.

When asked to detail positives comments for the e-tutorial, these included *it was informative, fun, varied, easy to use and above all helpful*; *I liked the use of diagrams and the drag and drop labelling was particularly helpful*; *A useful revision tool, especially for when you have done a lot of paper/book based revision as you loose interest after a while. I think I will retain what I learned better because it was more interactive*.

## 9.6 Discussion

This study has demonstrated that during a short 5-week elective Student Selected Component undertaken by medical students, it is possible to cocreate comprehensive educational and training packages made by students for students. The anatomical material was validated by one of the authors who is a senior clinical anatomist (PR). Help and advice was provide by one of the other authors (AL) in relation to the technical aspects of Articulate Storyline 2, and this author also provided full training for the students in its use.

Each of the three groups created detailed educational content in three individual areas of human anatomy, which are either interesting or complex to medical students. A variety of different tools were used in the creation of these tutorials from photogrammetry, Anatomy.TV, cartoon characters embedded into the tutorial, histology, clinical imagery and quizzes. These quizzes ranged from multiple-choice questions to insertion of text answers and drag and drop on images of various anatomical structures.

The pre- and post-evaluation questionnaires clearly established that there is a great need for e-learning resources by medical students who highly value the interactive nature as a learning tool. In this SSC, we have demonstrated the use of technology as a means to enable a constructivist approach to learning, creating an interactive learning resource that is effective in actively engaging students in their studies. The unique aspect of our approach was that the resources were actually created by students for students; working in partnership with the students ensures consultation with the end user of the resources enabling personalisation of their learning experience.

However, one thing that has to be kept in mind is that the feedback from the pre- and post-survey questionnaire statements has been entirely subjective in its assessment. To further this study, it would be useful to undertake formative assessment of anatomical knowledge both before and after the use of the e-tutorial. That would then allow for a formal comparison to be made of the further use of the tutorials.

Despite this, the tutorials have been shown to be a resounding success with student users. Indeed, the feedback from the cocreators of each tutorial has been highly complimentary of the SCC. They also felt that it had also improved their anatomical knowledge and understanding, but this was also based on subjective comments and not formal testing.

Over recent years, there has been a surge onto the market of electronic resources for anatomical and medical education. However, many of these resources are not tailored to any specific course or set of learning objectives. To allow students of a course to use their learning objectives for creating e-tutorials allows tailor-made resources, highlighting areas that the students feel need further emphasis which may be missed by faculty teaching staff.

Indeed, there have been significant advances in imaging techniques used to investigate patients with computerised tomography and magnetic resonance imaging (Hinshaw et al. 1977; Beckmann 2006; Geva 2006). Alongside this, there has also been more routine incorporation of modern imaging modalities into the medical curriculum from the anatomical perspective (Sempere et al. 2011). However, many educational and training products that are on the market have been created from a business perspective or, typically, not by students. This study highlights how we have engaged the student population by offering this Student Selected Component and how the educational resources were accurately generated over a relatively short time (5 weeks). The quality of the material generated was exceptional and was professionally reviewed. Therefore, the quality assurance was validated by professionals in their fields and was found to be of exceptional quality. We have also shown the ease in engaging the student population in the creation of these tailor-made educational and training packages created *by* students and *for* students that has resulted in a very popular resource for study and revision. Indeed, by engaging the student population, it demonstrates an active contribution to the learning process as well (Candy 1991). It also encompasses three of the major areas of self-directed learning, self-management, personal autonomy and learner control, and also encourages an independent approach to their learning (Hamer 2006). It also fits ideally with the constructionist approach to education generally and anatomy specifically (Ma et al. 2012). Thus, the creation of e-tutorials fits perfectly with this ethos.

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# Part IV
# Game Based Learning in Various Subjects

# Chapter 10
# Tipping the Scales: Classroom Feasibility of the Radix Endeavor Game

**Louisa Rosenheck, Jody Clarke-Midura, Susannah Gordon-Messer, and Eric Klopfer**

**Abstract** The Radix Endeavor is an inquiry-based educational game designed to encourage exploration and experimentation. Its design deeply integrates STEM practices as core game mechanics, enabling students to learn by doing in authentic contexts that are distributed across people, places, and time. Radix is a large-scale game that is not primarily designed to directly teach students math and science facts, but rather to serve as a foundational experience that teachers can integrate into their teaching in personalized and meaningful ways. Teachers have a difficult choice each time they consider implementing a unit of game-based curriculum. They must weigh the educational and pedagogical benefits on the one hand, and the barriers to implementation on the other, in order to decide whether the game is worth implementing in their classroom. In this chapter we discuss the feasibility of implementing the game in the classroom, teacher perceptions of student learning with the game, and the interaction between these two factors.

**Keywords** Game-based learning • Inquiry learning • MMO • Classroom implementation • Teacher experience

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## 10.1 Introduction

*Miss Parker is a ninth grade biology teacher. It's October and she is getting ready to start a unit on evolution. She has decided to try using the Radix Endeavor, an online game set in a virtual world, because she knows many of her students like games, and she's hoping it will allow them to work independently. She had them play through the game's tutorial quests in the last class so they should be ready to dig into the evolution quest line.*

*As students enter the computer lab, she asks them to log into Radix and start the evolution quest line by talking to Dar, the nonplayer character (NPC) who starts the quest chain, in The Menagerie. The students are excited to be in the computer lab rather than their science classroom. But there are a lot of questions in the first 10 minutes of class. Yadisha has forgotten her username, so Miss Parker reminds her where to look it up. Gabriel says his password isn't working, so Miss Parker uses the teacher dashboard to change it back to the default. Ariel's computer won't turn on, and Jonathan's computer can't get on the Internet, so Miss Parker asks them to sit with two other students and work together. A few students are messing around on their phones or on other web sites, so Miss Parker has to remind them to focus on Radix. Once the students are all successfully logged in, Miss Parker hopes they will be able to follow the gameplay smoothly, but as with anything outside of the normal routine, they still have questions:*

> *"Where do I find Dar?"*
> *"How do I get to The Menagerie?"*
> *"My game isn't loading … oh wait here it comes."*
> *"Dar told me to find menjis, what are those?"*
> *"Miss, is this right?"*

*Miss Parker moves from one student to the next trying to help them troubleshoot and also encouraging them to ask each other and try to figure things out on their own. She becomes a little bit frazzled from trying to answer everyone's questions without being completely familiar with the game herself. It's hard to find a balance between making the most of limited class time and not telling them exactly what to do.*

*After a while, the students settle in and figure out where to work on the first quest as they collect information about menji traits. Grayson seems to be figuring it out pretty quickly and frequently volunteers to help kids that aren't sure what to do. This gives Miss Parker a minute to log in to her Radix teacher account and check the teacher dashboard. Here, she is happy to see that most of the students have at least completed the initial task and are starting to make progress. She makes a note of the three students that are moving ahead quickly in order to have them give advice to others.*

*Once the students get into the grassland where the menjis are and figure out how to use the trait examiner tool, they start to actually think about menji traits. Miss Parker pays close attention to the questions and comments she hears among students:*

> *"I can't find any short-haired menjis, I think they are all long-haired."*
> *"Didn't you talk to Shiver? That's because it's cold around here. They need long hair to keep warm."*
> *"I found some short-haired menjis in the forest. If you need one I can show you."*
> *"How do I make a data summary for Dar? Who cares about this?"*
> *"Here, once you filter for grassland menjis, you can see that they're 90% long-haired. Then you can prove to Dar that's the special grassland trait."*
> *"You might not have enough menjis, try collecting like 20 and see if you can find out what they have in common."*

*Despite the fact that most students are just trying to complete tasks to check them off, they are also exploring the game world and starting to have conversations about traits and variation within a species. She can see this creating a foundation for when she formally teaches the concept of natural selection. Of course, the students' experience is not all fun and games. Some of them are quite frustrated with the quests. Jonathan and his partner are arguing over which tool to use and how to submit a data summary. Gabriel has thrown his hands up in frustration because Dar keeps telling him he doesn't have all the evidence he needs. And a couple other students are still asking Miss Parker which tools to use and which traits they are looking for. It's challenging for Miss Parker to give each student the guidance they need. But still she's glad they are having an experience that puts them outside of their comfort zone by challenging them to figure things out without detailed instructions.*

*With 5 minutes left in the class period, Miss Parker tries to help students reflect on their experience, good or bad. She tells them that what they're working on in Radix is not only learning about menjis or animal traits but about the scientific process. She has seen them trying things and making guesses, coming up with hypotheses and collecting evidence. She also tells them that even though they sometimes feel frustrated in this game, that's totally normal in Radix and many parts of life, and it is something they can learn to work through.*

*Miss Parker was apprehensive about the logistical difficulties and pedagogical challenges of implementing a large-scale digital game like Radix. While those things can indeed be stressful, she is also starting to see deep and unique learning emerge. She is already seeing more problem-solving and collaboration than in most of her class's activities. In addition, she sees it as an important skill for students to be aware of their own frustration and perseverance, and Radix is a venue where she can support them through that metacognitive process. So while she's not yet sure how she'll make time in her curriculum or come up with connecting activities, she feels dedicated to sticking with it and seeing how far students can go in Radix this school year.*

Situations like the one described above are starting to appear more often in today's classrooms. Game-based learning, where teachers integrate games into their curriculum and lesson plans, has been gaining popularity. For example, in the Joan Ganz Cooney Center's Level Up Learning survey, 74% of teachers said they use digital games for instructional purposes with their students (Takeuchi and Vaala 2014). Similarly, in the A-Games Project, 84% of teachers surveyed were at least moderately comfortable using games as a teaching tool (Fishman et al. 2014). Teachers from both samples reported using games for a variety of purposes such as covering content standards, teaching supplemental content, and conducting assessments. With the rise of interest and adoption, there has also been an increase in enthusiasm and optimism about the educational game market on the part of foundations and investors (Richards et al. 2013). The global learning game market continues to grow and is expected to reach $2.4 billion by 2018 (Ambient Insight 2014). While the market for these games in schools is much smaller, it continues to grow as well. Such growth and demand have been leading to the development of many new educational games, albeit of varying quality. As a result, this large pool of available learning games presents teachers with the challenge of identifying those games most appropriate for their students' needs. Teachers must consider things such as grade level, content standards, pedagogical style, device access, time frame, and much more. With such a large number of options, teachers have to be judicious about which games they try out in their classrooms and also about which games they come back to year after year.

In this chapter, we present a lens for how teachers make these decisions by balancing the barriers and benefits they see when implementing a game in their classroom, and we do so based on The Radix Endeavor as a case study. We will first describe the design and play experience of The Radix Endeavor game, as well as the intended and actual implementation of the game during the year-long pilot project. Then we will explore the pilot teachers' perspectives on the barriers and benefits they saw during their implementations of Radix, based on in-depth responses to interview and survey questions. From these game-specific perspectives, patterns emerge that form the lens we use to think about teachers' decisions on game-based learning more generally. Finally, this lens and the actual barriers and benefits that we see through it help us identify strategies that can increase adoption and improve implementation quality for teachers engaging in game-based learning.

## 10.2 Barriers and Benefits

Often times the first thing a teacher sees about a digital game or activity is the barriers to implementation. A variety of factors can make it challenging to implement a new learning game, even for tech-savvy teachers. The Level Up Learning report shows that the top five barriers teachers experience are insufficient time, cost, lack of tech resources, not knowing where to find quality games, and not knowing how to integrate games (Takeuchi and Vaala 2014). They may also need significant support in finding and using learning models that incorporate exploratory digital experiences (De Freitas and Neumann 2009). As we discuss later in the chapter, the teachers we worked with on implementing Radix in their classrooms reported similar concerns and barriers. While common, these barriers are also difficult to quantify or predict because they are specific to the environment in each school as well as teachers' personal preferences and comfort level.

Despite these barriers to implementation, there are also numerous ways in which games can add value to a curricular unit and provide students with a deep learning experience. Unlike traditional modes of learning, games can provide unique opportunities for strategic thinking and problem-solving, in the form of experiences that engage and challenge students over longer periods of time than most school curricula (Gee 2003). Games can also be successfully integrated into classrooms, especially when the classrooms adjust to accommodate interest-driven learning, multiple levels of expertise, and social experiences (Squire 2011). Numerous studies and meta-analyses have found value in teaching with games and simulations over traditional classroom approaches. This value can come in the form of higher cognitive and attitudinal outcomes, including increased self-efficacy and gains in knowledge and skills (Vogel et al. 2006; Sitzmann 2011; Wouters et al. 2013). Importantly, these benefits to learning are magnified in games with certain value-added features, that is, game features designed to support learning in conscious ways (Clark et al. 2015). In addition, it can be useful to categorize the impacts and outcomes of games as they vary depending on numerous factors (Connolly et al. 2012). Teachers who are interested in incorporating games into their curriculum are likely to be aware of these benefits, as well as the fun factor they can bring to the classroom. However, like the barriers, they are also difficult to quantify or predict because learning objectives depend on the type of game, the specific group of students, and a given teacher's style and priorities in lesson planning.

Barriers to implementation and educational benefits are the two overarching factors that teachers must consider in their evaluation of a game-based unit, even if they don't do so consciously. But as we have noted, these factors are highly dependent on the context and preferences of a teacher and her classroom. Therefore, it is really teachers' perceptions of these key factors that form the basis of their decisions to use, or continue to use, a given game in their classroom. There is a natural tension between these two, which teachers must balance in order to make it worth the time and effort of implementing a digital game. While this decision-making process was observed in the context of Radix teachers, it is likely to apply to the evaluation of other similar learning games as well. We can picture barriers to implementation and educational benefits as two axes, as shown in Fig. 10.1. From there, a teacher could rate the learning games he is considering according to his perspective on the barriers and benefits and then place the games somewhere along each spectrum. When we look at it this way, it becomes fairly intuitive that games that fall in the top-left area of the graph (high benefit, low barriers) would be a good choice to use in a classroom. Similarly, games that fall in the bottom-right area (low benefit, high barriers) are also easy decisions, since there is no good reason to use them. It is the games that fall somewhere in the middle area that are much harder to evaluate and depend greatly on the teacher's individual situation. Some teachers are always up for a technical challenge, while others shy away from them. Some teachers greatly value problem-solving skills, which may be best taught by a certain game, while others may feel they can get at that just as well through paper-based activities. The element that tips the scales in favor of using or not using a game will be different for every teacher in every school. Given the complex ecosystem of

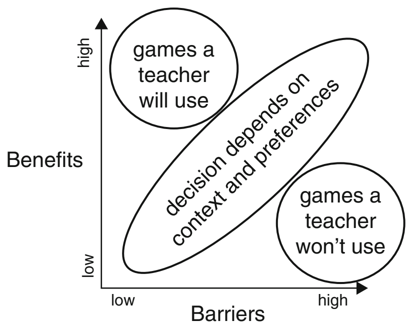


**Fig. 10.1** Decision-making process for evaluating learning games for the classroom

teachers, schools, and games, there are many layers to understanding the different ways teachers might evaluate a game and its implementation.

## 10.3 Background

### *10.3.1 Design of the Radix Endeavor*

This decision-making process was one area of focus in our research on The Radix Endeavor (www.radixendeavor.org), an inquiry-based online game for STEM learning developed at the MIT Education Arcade. Radix is set in a virtual multiplayer world with embedded biological and mathematical systems that involve the world's flora, fauna, and fictional civilizations. Players take on quests that guide them to probe the game's systems and develop a firsthand understanding of math and biology concepts in a variety of topic areas. The game is exploratory, leaving a lot of experimenting and problem-solving up to the players. It incorporates a wide variety of content as well as STEM practices and even soft skills. Rather than teaching players directly, it builds a conceptual understanding, leaving students open to make connections between experiences in the game and experiences in their classroom and even their lives outside of school. It is a long-form game, meant to be played over the course of a semester and revisited during each relevant curricular unit. In addition, it presents opportunities for players to collaborate both in and outside of the game, leading to a unique deep learning experience.

To support these goals, the central Radix gameplay is designed around systems that players can interact with and manipulate. Figure 10.2 shows players in the forest region, one of the five distinct biomes with unique fauna, flora, structures, and characters. In each of these biomes, players can engage in activities such as collecting data to compare the heights of plants in different regions. They can also experiment with simulations to see how a species in a biome has evolved over time and manipulate variables to test out changes in the environment, as seen in Fig. 10.3. Players have a variety of tools that allow them to engage in the authentic practices of biologists and mathematicians. Some of the tools are open-ended and creative, allowing players to draw geometric objects on scale maps, build fences, or create and share food web diagrams. The gameplay is centered on quests that target specific content areas in biology and math. These quests are designed to encourage players to explore the different systems and biomes as well as to engage in inquiry, problem-solving, and collaborative learning in order to complete the task and provide evidence needed to support their solution.

When a new player enters the Radix game, she finds herself in a grassland biome on the island of Ysola, an earth-like world full of fictional plants and animals. She is likely to see the avatars of other players moving around the world working on tasks in the same area. There is a character nearby with an exclamation point over her head, so she talks to her to take on her first challenge, which starts the series of


**Fig. 10.2** Radix players exploring the forest biome

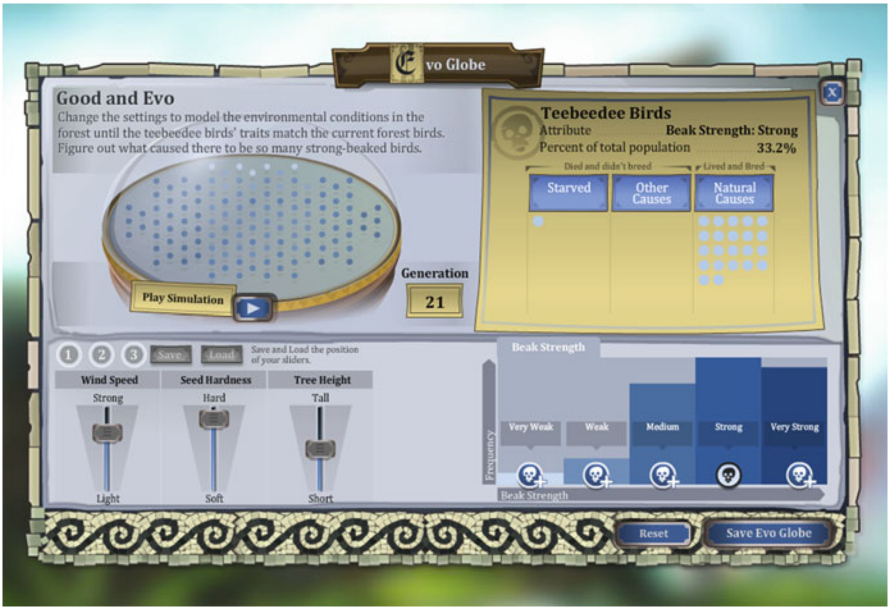


**Fig. 10.3** The evo globe tool lets players simulate changes in a trait over time

introductory quests. Once she has completed those quests, she will be familiar with navigating the world, talking with in-game characters, and using the basic tools for collecting objects, examining them, and analyzing data about them. From there, a wide array of other quest lines is unlocked. The player can explore any topic area she is interested in or the specific ones that her teacher has asked her to work on. Each quest line starts with one of the island's residents explaining some problem or question that is causing the people trouble. This way, the game's challenges are situated in a contextual narrative that gives the player a reason to care and a motivation to solve problems that will save the island or its people. The player will then use her tools to explore the environment, ostensibly "messing around" but in reality experimenting and making discoveries. Through collecting and analyzing data, the player gains an understanding of the mathematical and biological systems embedded within the game world, such as Mendelian genetics or evolution. Once she understands each system, she can adjust the inputs to that system in order to get the outputs necessary to solve the problem. She then returns to the character in need of help to turn in an artifact or explain a solution, which requires not only an answer but also data that explains how she knows her solution will work. Quests take place across the Radix world, with different tools becoming useful in different domains.

The virtual Radix world provides an environment where students can gain both content knowledge and the skills and practices critical to STEM fields. The game covers topics in biology (genetics, evolution, ecology, human body systems) and math (algebra, geometry, statistics) which were carefully selected to complement what students can already do in a hands-on lab or classroom setting. The particular content for each of the topic areas is aligned with standards from the Next Generation Science Standards and Common Core State Standards, including an emphasis on science and math practices. These include things like model building, investigation, interpreting data, and evaluating information, which are incorporated into game tasks. In addition, the game creates a space for students to practice inquiry, meaning that when players encounter a problem in the game, they must think through how to solve the problem and determine their own course of action. For example in the evolution quest lines, players collect data about the traits of animals in different regions of the world in order to learn about adaptation. They have a known question to investigate, looking at the various traits in the menji species, but they must figure out for themselves what process to use to do that. As the players examine menjis in different regions, they study patterns, interpret data, and construct explanations. In this and all of the quest lines in the game, players must use twenty-first-century skills such as collaboration and critical thinking in order to solve problems. This emphasis on skills and practices is critical to students as they learn concepts from science and math, and Radix provides an innovative place for students to engage with these skills.

### 10.3.2 Implementation Design

Radix was not designed to be a stand-alone game, but rather as a supplemental tool for teachers to use in conjunction with other curricula and activities. Its design and implementation drew inspiration from the preparation for future learning approach (Schwartz and Martin 2004), where one learning experience is made more impactful because of subsequent relevant experiences. It was designed for students to first play and explore and then reflect, with the reflection piece being critical for their learning. For example, in the genetics quests, students explore the traits and varieties of different species in the virtual world, experimenting with different genetic crosses and the resulting offspring, shown in Fig. 10.4. However, the game does not explicitly mention genotypes and phenotypes or directly explain the relevant inheritance patterns. It is up to the teacher to do this through classroom discussion, small group work, or individual student reflection. The game provides students with hands-on experiences of the systems that they can later connect to vocabulary and concepts through discussions. For example, a teacher may say, “Remember in Radix when you were breeding glumbugs and you had babies with medium antennae, not only long and short? That is an example of incomplete dominance.” The role of teachers in implementing Radix is to help students form these links and provide the time and space for reflection during gameplay.

Enabling rich connections, usually fostered by a teacher or facilitator, is a key element to Radix. To support teachers in this, a number of important resources were


**Fig. 10.4** Players experiment with inheritance patterns to breed a specific trait

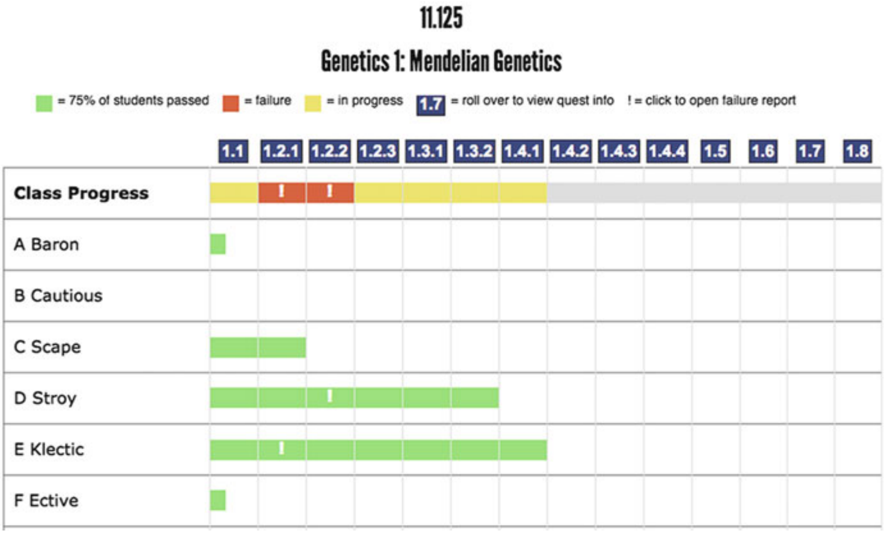


**Fig. 10.5** Teachers can track student progress in the game

provided to them within a teacher dashboard. Standards and practices covered in each quest line are clearly listed, along with video tutorials for those quest lines and relevant tools. A set of "connecting questions" is provided for each quest so teachers can help students reflect on their gameplay experience. And, as shown in Fig. 10.5, they can track students' progress in the game in real time, with focused information provided around students' "quest failures." When Radix launched, teachers were offered both online and face-to-face professional development, much of which focused on the inquiry-based nature of the game. They also had access to webinars and virtual office hours throughout the pilot period, which provided a chance to vent frustrations, share successes, and get help from staff and peers.

This variety of resources was designed to help teachers plan and implement Radix in their classroom, whether or not they were already comfortable with game-based learning or inquiry games for learning. Radix is different from many other games more commonly used in the classroom in a number of ways. Some of the top games seeing a lot of adoption are coming from sites such as Starfall, Cool Math, PBS Kids, and BrainPOP.(Takeuchi and Vaala 2014). Those and other games commonly used in the classroom tend to be short form, fitting easily into one class period, and they tend to focus on a more narrow topic area (Richards et al. 2013). Radix, on the other hand, integrates many larger or more abstract concepts across domains into one game. For that reason, and in order to foster deeper learning supported by reflection time, it is designed to be experienced over many sessions, throughout a number of curricular units. Whereas with some educational games, teachers can quickly tell if students have learned something; a game like Radix takes more time and thought to tease out how students are interacting with the game world and with each other. These factors mean that there is a wide variety of implementation styles, including formats and approaches, that can be used successfully depending on the teacher's views and school context (Rosenheck et al. 2016).

When they signed up for the pilot, teachers were given several suggested implementation models. These focused on a student-driven, curriculum-integrated approach. We encouraged teachers to have students play on their own time, ideally outside of class either at school, at library, or at home. This would mean students could explore at their own pace without the pressure of their peers or a timed setting, driven by their own goals and interests. It would also enable teachers to use precious class time for facilitating reflection and making connections, based on the shared experience students already had. To go along with the independent play, teachers were encouraged to assign a particular quest line according to the unit they were currently teaching (i.e., genetics or congruent triangles) and to encourage their students to work on other quests if they were unlocked and then help them draw connections between topics and even subject areas. To capitalize on the principle of preparation for future learning, it was recommended that teachers have their students play the relevant Radix quests prior to formal instruction in that topic, or at least early on in the unit. They could follow this pattern throughout the school year, asking students to come back to the game and play the relevant Radix quests in preparation for each unit. This is how we envisioned teachers would be best able to deeply integrate the game into their curriculum and create a meaningful and unique learning experience for their students.

### *10.3.3 Implementation Realities*

Naturally, the implementation choices teachers actually made spanned a wide range of possibilities. Many teachers felt they had to use class time to play the game because their students didn't have access to computers outside of school time. Some gave their students complete free reign as to what area of the game to explore, whereas others gave very specific requirements and disallowed other quests. There were teachers who used it as an introduction to material, some who used it during a unit, and some who used it as review or even an assessment at the end of a unit. Some used only one quest line, while others had students play the material freely over the course of several months. Some created their own bridge materials to draw out students' strategies and ideas from the game, whereas others didn't conduct any additional activities. As in any large-scale implementation project, this variety of implementation choices was not unexpected, and this range of methods was one focus of our research on the Radix game.

The variation from the suggested approach, and the additional approaches that were used, had a huge impact on teachers' perceptions of feasibility of the game. These significant pros and cons of implementing Radix in a classroom are the inevitable trade-offs of a large-scale educational game. Because of this, we wanted to look closely at why teachers were excited about and frustrated with Radix. In order to understand what goes into their decision to implement or continue to implement this game, we collected data from Radix teachers on what they saw as the barriers of implementation and what they saw as the biggest benefits based on their experience. The interplay of these factors provides a lens for us to look at both the implementation of Radix, specifically, and the way that teachers evaluate games more generally.

## 10.4 Research Design

Radix launched as a free tool available across the USA and internationally in late January 2014. Teachers were encouraged to sign up for an account and begin to use the game as they saw fit in their classroom. During the pilot period which ran through August 2015, Radix had over 18,000 user accounts and was being played in all 50 states and seven different countries. While the game was designed with high school math and biology teachers in mind, Radix has been used by upper elementary, middle, and high school teachers as well as by a few instructors at community colleges and universities. Outside of the formal school environment, the game has also been picked up by various after-school groups, enrichment programs, and the homeschool community who are using it with a wide variety of ages.

The research presented in this chapter was part of this larger pilot which collected a wide range of data including what students did in the game (log data), pre- and post-assessments of content, student interviews, teacher interviews, teacher surveys, and classroom observation data. Teacher interviews and surveys were the instruments that provided the most insight into teachers' perceptions of Radix and how they decided whether to continue implementing the game. In addition, some of the log data linked to teacher accounts helped describe teachers' use of the game as well. Therefore, these are the data types this study will focus on.

### *10.4.1 Sample*

Our sample of teachers included in the pilot study falls into two groups. One is the larger group of all the teachers that used Radix ($n = 2125$). However, when we analyze more specific metrics such as the number of classes created or the average playtime for a teacher's students, we see that many of the teachers who created accounts never took any of these actions. Therefore, the sample size for each metric becomes much smaller and is noted within the analysis.

The second group of teachers is a subset of the larger group, and this is the group of teachers that had Radix accounts and also participated in an interview and/or survey. There are 37 teachers who fall into this category. Of these teachers, 15 taught at the high school level, 15 at the middle school level, and 7 in after-school programs

**Table 10.1** Number of participants in each study group

| | Teachers | Schools | Classes created | Student accounts |
|---|---|---|---|---|
| All teachers | 2125 | 1765 | 981 | 11,772 |
| Subset of surveyed teachers | 37 (five of whom could not be mapped to usage data) | 28 | 103 | 1927 |

or other settings. The number of schools, classes, and students associated with each sample is shown in Table 10.1.

## 10.4.2 Data Collected

### 10.4.2.1 Log Data

We collected information on the game's back end about student usage. Student usage is nested by class and teacher. This provided information about how much and how often teachers used Radix with their classes. In addition, every time a teacher assigned a quest line to a class through the teacher dashboard, that data was logged. During that interaction, teachers were also required to fill out two poll questions:

1. How do you plan to use this? (homework, in class, other)
2. When is it being used? (pre-unit, during unit, post-unit, other)

### 10.4.2.2 Surveys

We administered a teacher survey post-implementation. The teacher survey was a mix of closed- and open-ended questions asking teachers to report on the following areas: educational and teaching background, Radix implementation details, views on ease of use, classroom experience with Radix, and observed results. Teachers were asked to take the survey after they were completely done with their Radix implementation for the school year. The survey was publicized in the monthly Radix newsletter sent out to all teachers with accounts by providing a link to an online survey. Teachers were encouraged to take the survey regardless of whether their Radix experience had been overall positive or negative, and participants were entered into a drawing for a gift card. However, the teachers that actually took the time to fill out the survey were a self-selecting group which resulted in only 55 responses. Once incomplete and duplicate responses were cleaned out, we had 37 survey responses.

Out of 26 total questions, nine were open response, and those answers were imported into the qualitative data analysis software Dedoose. Two researchers worked collaboratively to code the responses. They started by developing a unique set of codes for each question that would categorize that question's responses in meaningful ways. They then each coded five responses for each question according to the preliminary coding system. Next they compared the codes assigned to each response and discussed any discrepancies. This helped refine the coding schema by informing additions and subtractions to the code set as well as highlighting places where the code definitions needed to be clarified. Once the coding schema could be consistently applied, the two researchers split up the remaining responses and completed the coding process. Finally, we took advantage of Dedoose's analysis capabilities to understand the participants' views on each question. This lets us see what were the most common specific responses (as opposed to generic responses that didn't mention any identifiable aspect of the experience) as well as dig deeper into what exactly teachers said about their experiences in each area.

#### 10.4.2.3 Interviews

The teacher interview was the most in-depth of the data collection methods. Following a semi-structured format, the 15 interview questions covered topics in teachers' background, Radix implementation, support used, fit with curriculum and teaching methods, and feasibility. The prepared protocol helped the two interviewers conduct interviews consistently while also allowing participants to bring up aspects of their Radix experience that were important to them. As with the survey, interviewees were entered into a drawing for a gift card, and the opportunity was promoted through the monthly Radix newsletter. As participants were largely self-selecting, they ended up coming mostly from the subset of teachers who had been in closer contact with or had been visited by Radix staff. The 15 teacher participants were interviewed during the late spring of 2015 after each one had completed their Radix implementation for the year. The length of the interviews varied from around 20–45 minutes depending on how much the teacher had to say about each topic. One interview was conducted in person, including two teachers simultaneously, for practical purposes. The rest of the interviews were conducted over the phone, using WebEx software to record the conversations. These recordings were then sent out to a transcription service, so that the text of the interviews could be imported into the Dedoose software.

Once the data was set up in Dedoose, we used the same coding process as we did with the open-ended survey responses. For the interviews, we designed a specific coding schema for each question, along with a more general set of overarching theme codes that could be applied across questions. Because teachers' discussion topics tended to overlap more in these casual interviews, this helped us analyze specific questions across participants, while still getting a sense of the big picture themes that ran across all aspects of teachers' experiences.

### *10.4.3 Data Analysis Goals*

The data collected from the surveys and interviews, being that they were all self-reported by teachers, were not meant to tell us about the efficacy of the game or give any standardized ratings on feasibility. Similarly the goal in coding the qualitative data was not to have an objective outsider judging or rating any aspect of the teachers' implementations. Rather, the goal was to give teachers the opportunity to share what was important to them about their experiences with Radix. We wanted to understand how teachers see these factors and what relationships exist between factors. This was the approach we took to gathering data on teachers' perspectives and understanding more about the decision-making process when it comes to using or continuing to use a large-scale learning game like Radix.

## 10.5 Findings

### *10.5.1 Background*

#### 10.5.1.1 Feasibility and Usage

In order to get a general sense of how much teachers used Radix (regardless of implementation style) and whether they thought it was feasible, we first looked at some broad indicators. These included two questions from the teacher survey ($n = 37$) along with data collected through student gameplay.

In response to the question "Do you see usage of Radix in typical school settings as feasible from a practical perspective?" 59% said yes and 38% said no. This indicates that while many teachers in our sample do feel that Radix can be implemented in the classroom, there are still a large number who see too many barriers to make it a practical educational tool.

In response to the question, "Do you plan to use Radix again in the next school year?," 43% said yes, 46% said maybe, and 8% said no. This is interesting because despite the fact that 38% of respondents feel it is not feasible, only 8% said they would definitely not use the game again. In fact the largest group were the teachers who were unsure whether they would continue using Radix, suggesting that there are tensions at play which make the decision a difficult one.

We then wanted to see if these responses had any correlation with how much teachers used the game during the pilot period. While gameplay data does not explain how or why teachers used the game, it does set a baseline for how much their students interacted with the game. We selected three main metrics to describe teacher usage:

- *Number of quest lines assigned*: Radix contains 16 quest lines that students can play through, and there is a mechanism for teachers to assign these quest lines to their students which is then indicated when students log in. Teachers don't have to assign quest lines in order for students to play them, but when they do that, data is logged and tells us something about how much teachers are asking their students to do.

**Table 10.2** Teacher usage metrics combined with survey responses ($n = 32$)

| | Average number of quest lines assigned | Average time span of quest activity (in days) | Average quests completed per student |
|---|---|---|---|
| *Do you see usage of Radix in typical school settings as feasible from a practical perspective?* | | | |
| No | 2.58 | 152.72 | 13.98 |
| Yes | 4.21 | 158.76 | 14.01 |
| *Do you plan to use Radix again in the next school year?* | | | |
| No | 2 | 103.15 | 5.27 |
| Maybe | 3.15 | 129.91 | 13.11 |
| Yes | 4.27 | 188.17 | 16.56 |

- *Time span of quest activity*: Each quest action a student takes in the game is logged and each student is associated with a teacher. The time span of quest activity for a given teacher is the number of days from the first time one of that teacher's students completed a quest action to the last time one of their students did. While there may be stretches in between where no one played (and there usually are), this metric gives a sense of whether a teacher used Radix for only a month or throughout the whole school year.
- *Average number of quests completed per student*: The database tracks how many quests each student has completed, and this metric is the average number of quests completed across all of a given teacher's students. This includes everything students worked through in the game, regardless of what the teacher assigned them to do.

The combination of these usage metrics with the survey questions on feasibility and future use is shown in Table 10.2. We can see that in each metric, Radix was used more by teachers who felt the game was feasible to implement. Similarly, teachers that were planning on using the game again had also used it more with their students. This makes sense because teachers who had a harder time implementing Radix in their classroom may have ended up using it less during the pilot period and may also therefore be less likely to continue using it.

When looking at this and subsequent data to be presented, it is important to keep in mind that the subset of Radix teachers who took the survey were a self-selecting group. Among teachers who used Radix, to see if there were differences between the teachers who did and did not take the survey, we compared these same metrics between those two groups. As shown in Table 10.3, in each metric we see more usage on average from the survey participants than from the other teachers who used Radix. This is most likely because the teachers who used Radix more were more involved with the project or more enthusiastic about the game and therefore more likely to take the time to fill out the survey. This means that as we look at more detail about what teachers saw as barriers and benefits, we know that information is coming from a somewhat more engaged group of teachers.

**Table 10.3** Differences in usage metrics across sample groups

| | Average number of quest lines assigned | Average time span of quest activity (in days) | Average quests completed per student |
|---|---|---|---|
| Teachers that took the survey | 3.5 | 153.65 | 13.61 |
| | $n = 32$ | $n = 32$ | $n = 32$ |
| Teachers that did not take the survey | 2.7 | 52.36 | 8.86 |
| | $n = 249$ | $n = 274$ | $n = 264$ |

**Table 10.4** Teacher comfort level broken down by future usage plans

| How comfortable were you with the idea of using Radix | Mean comfort-level rating |
|---|---|
| Before using Radix? ($n = 37$) | 2.3 |
| After using Radix? ($n = 37$) | 2.9 |
| Plan to use Radix again ($n = 16$) | 3.4 |
| Do not plan to use Radix again ($n = 3$) | 2 |

#### 10.5.1.2 Comfort Level with Radix

Teachers were surveyed about their comfort level teaching with new software, as well as with Radix. They responded to statements on a scale of 1–4 where 1 = not very comfortable and 4 = very comfortable. When asked "Before using Radix, how comfortable would you say you were in using new computer software in your teaching?," their average rating was 3.4. However, when asked "Before using Radix, how comfortable were you about using Radix in your teaching?," they reported an average rating of 2.3. This difference in comfort level between software and a game could be due to the fact that many teachers often choose more targeted, easier to implement software, whereas Radix is an open-ended game. A lot of emphasis in implementing Radix is put on the inquiry features and integration into curriculum, which may feel more difficult to teachers. Interestingly, when asked about comfort level with Radix after having used it, teachers reported an average rating of 2.9. Within this group of teachers surveyed about their comfort level after using the game, the teachers who said they did plan to use Radix again reported a mean of 3.4, whereas those who did not plan to use it reported a mean of just 2 (Table 10.4). These results suggest that individual comfort level may play a role in a teacher's decision to implement a game in the classroom. More broadly, it speaks to the importance of providing support and scaffolding for teachers trying new kinds of game-based learning, in order to mitigate some of the comfort-related barriers teachers may face, and increase the likelihood that they will feel comfortable continuing to use the game with their students.

**Table 10.5** Teacher ratings of ease of administrative tasks ($n = 37$)

| Task | Rating (1–4) |
|---|---|
| Creating classes in the teacher dashboard | 3.4 |
| Adding students to a class | 3.4 |
| Assigning quests in the teacher dashboard | 3.2 |
| Monitoring class progress in the dashboard | 3.1 |
| Monitoring student failures in the dashboard | 3.1 |
| Reserving class gameplay time in the dashboard | 3.4 |

**Table 10.6** Teacher ratings by quest line ($n = 37$)

| Quest line | General ease of implementation rating (1–4) | Ease of figuring out and playing quest line rating (1–4) |
|---|---|---|
| Algebra | 2.6 | 2.5 |
| Geometry | 2.6 | 2.2 |
| Statistics | 2.9 | 2.4 |
| Ecology | 2.9 | 2.6 |
| Evolution | 3.0 | 2.8 |
| Genetics | 2.9 | 2.7 |
| Human body systems | 3.3 | 2.8 |

#### 10.5.1.3 Ease of Implementation Ratings

Teachers were asked to respond to statements about how easy or hard specific aspects of Radix were to implement in their teaching on a scale of 1–4 where 1 = very hard and 4 = very easy. Statements included administrative tasks necessary for using the game, such as assigning quests and using the teacher dashboard. As shown in Table 10.5, the average ratings for every aspect were higher than 3, suggesting that these administrative tasks were not barriers to implementation.

Similarly, teachers were surveyed about how easy or hard each quest line was to implement. They were asked to respond to statements on a scale of 1–4 where 1 = very hard and 4 = very easy. Table 10.6 shows that on average, teachers reported that quest lines are more difficult to implement than the administrative aspects. Some quest lines, such as algebra and geometry, were harder to implement. However, most of the quests were reported as easy to implement (average comfort level $\geq 2.9$ ). It is important to keep in mind that what it means to "implement" a quest line varies from teacher to teacher. Overall, this suggests that implementing a quest line is probably not the biggest barrier to implementation.

However, when asked more specifically about how easy or hard each quest line was to figure out and play, teachers did report difficulty with some quest lines. As shown in Table 10.6, the average ratings ranged from 2.2 to 2.8 which suggests that compared to implementing quest lines in general, getting into the details of quest content and gameplay proved more difficult for teachers. One possible explanation for this is the time it takes to learn the tools and play through quests. As an MMOG, Radix provides many areas to explore and a variety of ways to use tools, which supports its inquiry learning goals. Squire (2011) discusses the value of long-form game experiences and shows examples of how these games can still be successfully integrated into traditional classrooms. But it is not an insignificant task for teachers to learn the game well enough to feel comfortable teaching with it.

### *10.5.2 Implementation Barriers*

The survey responses provided us with some general feedback; however, we turned to our interviews and open response questions to understand how and why challenges to implementation may exist. We looked across the data and identified common themes that teachers identified as barriers. We identified seven main types of challenges they grappled with:

1. Technical issues
2. Curriculum fit
3. Gameplay reports
4. Teacher and student resources
5. Level of control over student actions
6. Amount of time needed
7. Level of boredom or frustration for students

In the rest of this section, we will describe what the data says about each of these barriers and how they affect teachers' opinions on feasibility and decisions on using the game. As we look at each one in more detail, it is important to keep in mind the complex system of the school environment – these and other factors are interconnected and can often exacerbate or mitigate each other.

#### 10.5.2.1 Technical Issues

Technical difficulties were the most often cited problem teachers faced when implementing Radix. When asked to explain "why Radix is or is not feasible to use from a practical perspective" on the survey, 7 out of 19 (34%) specific responses given about negative aspects were related to technical issues. In addition, 5 out of 14 (36%) teachers that were interviewed brought this up when asked what difficulties they encountered while using Radix. When asked more specifically about "what frustrations or difficulties you experienced due to technical issues," teachers mentioned difficulty logging in and loading the game, problems with hardware in their lab not working right, slow Internet or networks that were down, and trouble getting the teacher dashboard to work as expected. Clearly, these issues span both bugs and design issues within this specific game, as well as lack of infrastructure within the schools. While in some cases these barriers make it obviously impossible to have students play an online game, there are many more cases where it's not impossible but the frustrations overshadow any benefits in the game. Teachers that have some students playing the game and others stuck on broken machines would have a much harder time keeping their class in sync. Teachers that get their class into the computer lab only to find out the Internet is unreliable that day are less likely to plan to try that lesson again. Teachers that spend the whole class period struggling to help students find their usernames and reload the game until it seems to be working can hardly be expected to find it a good use of their time. As one participant summarized, "It is complex for me to deploy activities for students and I can't use all the potential of the game." Some of these technical issues are related to other factors, such as initial comfort level with technology and availability of IT resources, but the end result of what teachers experience when they try out the game is something they must consider as they plan their game-based curriculum.

#### 10.5.2.2 Curriculum Fit

When surveyed about how "the Radix curriculum fits within your plans for curricular objectives, standards, and student learning," 18 out of 32 (56%) responses were categorized as not fitting well ($n = 5$) or fitting only somewhat well ($n = 13$). Of these responses, many mentioned their students being at a younger grade level than the game content. This is interesting because it demonstrates that those teachers were willing to try an intervention that they knew was targeted at a higher grade level, even if that factor ultimately influenced their decision to not use Radix further. Other responses mentioned the need to evaluate individual areas of the game separately, such as the teacher who said, "Part [sic] of it are strong, other parts are weak. As a teacher I need to pick and choose the stronger, more aligned parts for use with my students." This is a task unique to larger games that have an array of topic areas and content levels within them. Another teacher remarked, "The jury is still out on this for the teaching I do. I am very interested in how I could integrate Radix into my curriculum, but I need to do more work and planning on this." Both of these sentiments show that evaluating the appropriateness of a complex game's curriculum takes some thought and is not as simple as matching standards on paper.

#### 10.5.2.3 Gameplay Reports

One common issue that emerged through the more in-depth interviews was teachers' desire for more detailed reports on what their students were doing and learning in the game. When discussing "the biggest difficulty you had in implementation," concerns around the feedback provided to teachers were one of the five main recurring themes. Similarly, when asked about additional support resources they would like to see, the request for more detailed feedback was also one of the three recurring themes there. What teachers are referring to is more information about what students are doing in the game, what they are getting right and wrong, and what they are learning. While the Radix teacher dashboard did provide basic information on student quest progress and a small amount of detail on their quest attempts, the need for more detail on how long students had worked on certain tasks and what tools or features they were using in the game was a popular request. One teacher said, “It’s nice to see how students perform on the puzzles, but I want a lot more data than Radix gave me. I feel like I didn’t have enough specific information and I would have liked more. I’m glad that you gave me something, but more than they failed or they got this percentage.” This indicates that teachers feel that more information is empowering and a key factor for them to be able to implement Radix and support their students effectively. Of course this role of student data is closely tied to how teachers plan to use that data to tailor their instruction and what approach they have for integrating the game into their curriculum. Overall, in a more student-directed learning experience such as an inquiry-based game, teachers may need that information to feel like they have a good pulse on the classroom, regardless of how they plan to use the data. The amount and type of reports a teacher can get on an individual student level are therefore a major factor in teachers’ experience of implementing game-based curriculum.

#### 10.5.2.4 Teacher and Student Resources

When asked what additional support resources teachers would like to see, one of the three recurring themes was more teacher feedback as described above. The other frequently mentioned needs were additional resources for teachers, and for students. This included an occasional mention of teachers who would have liked more opportunities to attend professional development sessions and learn how best to teach with Radix. However, the majority of responses about the need for resources were more focused on learning the game and using all of the tools and features in the game. For example, how to get around the world, what the sequence of quests was, and what content was covered in each quest – these are the things that teachers preferred to have written down explicitly and in a format they could share with their students. One teacher described the need for training this way: “I guess it’s one of those that it feels like you almost need to play a little bit yourself to really get a sense of it. So if it were like one of those teacher workshop-type things where, ‘Here’s a little overview of it and here’s the main goals, here’s how to set up, here’s how to assign the quests to your class and here’s what it feels like to play it a little bit’ to sort of help me get my feet wet and to know what to emphasize to my class students.” And another specifically mentioned wanting ready-made student resources: “I had difficulty with the implementation. I felt like I needed some sort of handout to have my students answering as they worked through the quests. I had hoped that there would be some ancillary materials that would be print and go so that I could focus my students attention with out [sic] having to spend extra time developing materials myself.” These responses show that simply providing a good game, even if it has robust data collection tools built in, is not enough to make it feasible to use. Part of the inquiry-based nature of Radix requires students to experiment with tools and figure things out on their own. However, this can be difficult in a time-limited class period, and it is also a big leap from the traditional teaching methods being used in many classrooms. Before teachers have made the leap from acting as a traditional teacher to more of a guide, factors like this often contribute to teachers' desire for more handouts and proscripted materials. Therefore, from their perspective the offering must also include significant resources to help teachers learn the game and learn how to use the game, along with resources that teachers can provide to their students to learn the game.

#### 10.5.2.5 Control over Student Actions

When asked generally whether Radix was feasible to use, the second most commonly mentioned factor (after tech issues) was a need for more control over students' gameplay. These accounted for 5 out of 19 (26%) specific negative responses. This theme also emerged in a variety of other questions about implementation style, engagement, etc. There were mentions of wanting to limit students' access to the chat feature, but also more general restrictions requested in terms of when students can access the game, where they could go, and most popularly which quests they could work on. When a teacher assigns a quest line in Radix, students are directed to work on those quests, but the other quests are still accessible, so students can explore things that interest them. There are pedagogical reasons for this design, but there are also trade-offs as this teacher described succinctly: "There is so much freedom inherent in the game structure that too much time is spent wandering around and not actually doing anything productive." This is why another teacher described this as her requested feature: "I understand the reason why we want kids to be able to go off and do these other quest lines, but I almost wish while I'm using it in the classroom, I could sort of shut those down temporarily while they're finishing something and then open 'em back up." Building on the desire for more data and feedback, these responses show that teachers not only want to know what students are doing in the game but they want to be able to control what students can and can't do in the game. Like the requests for more resources on how to play in a school environment with practical constraints around time and technology, it is logical for teachers to feel that they must make the most of students' in-game time. This is especially true given the learning curve for students themselves to function in an open-ended environment when they are used to very structured schoolwork. In the beginning, teachers may feel that students are not using their time well or being productive in their explorations. Therefore, whether or not teachers are on board with a student-centered, inquiry-based pedagogy, the ability to direct their students within an activity will always play a role in how they fit a game into their curriculum.

#### 10.5.2.6 Amount of Time Needed

The problem of not having enough time was the third most common response to the survey question of whether Radix was feasible to use, with 3 out of 19 (16%) mentions of negative aspects. This issue also popped up in responses to other questions, with 5 out of 14 (36%) teachers bringing it up when interviewed about what difficulties they encountered while using Radix. Comments included not having enough time for the teacher herself to sit down and learn the game and not enough time to pore through the teacher dashboard to figure out what students had been working on, but the main issue was not having enough time for students to play the game. Within that there are still a number of variations – not enough time with access to the computer lab, class periods that were too short, not enough time in the curriculum to spare a few classes playing Radix, and not enough time to complete quest lines because students may have taken longer than teachers expected. This teacher knew that her implementation could be better if she had more time to make connections and help students reflect, as she said, “I wish I had more than 40 minutes sometimes. Because a lot of times, you’d have to end it, kinda like a fire drill. You didn’t have the time to really discuss it.” Whereas this teacher felt more time was needed for both her and the students: “As far as implementation, time for me to sit down and get to know the program one. Time for the kids to play the program, because as I stated earlier, I only get to see these kids one day a week for 200 minutes, 200 minutes that’s it.” These various ways that time limits can be a barrier show that not only is it a serious constraint but it is a complex one. Giving a teacher more class time or more prep time wouldn’t necessarily solve this challenge with game-based learning because there are so many aspects that could benefit from longer chunks if not more total time for implementation. The reality is that for student-centered, inquiry-based pedagogy, including game-based learning, to be done well, it often requires more time than the current school timetables allow.

#### 10.5.2.7 Students’ Boredom or Frustration

There is an assumption that all games are fun; however, this is not always the case (Squire 2011). So it is no surprise that when discussing negative aspects of using Radix, 3 out of 19 (16%) comments alluded to the fact that their students were bored or frustrated. In addition, 8 out of 14 (57%) teachers who were interviewed about difficulties in implementation brought up issues related to engagement and student attitudes. This category of response included teachers describing students as bored, frustrated, distracted, or floundering. In some cases this may have been part of the natural process of students’ getting used to exploring an open-ended world. However, from the perspectives of many teachers, these were barriers to student engagement and therefore challenging to the implementation. Often times these attitudes were caused or exacerbated by other implementation challenges, inherent to either the game or the school environment. For example, one teacher’s students found the game world difficult to explore: “They never got good at the navigation process. They never really understood it and so, they just came to just despise Radix because they knew that anytime they'd get in there, they'd get lost, and they'd get stuck, and they wouldn't know what to do and that's tough." Whereas another teacher identified technical issues as the root cause: "Software on computers and internet connection made the lag time too long for my students. Off task behavior and disinterest from students followed in class assigning of Radix quest lines." Here again the interplay of various barriers emerges, highlighting the fact that teachers' view of the success of an intervention is a complex one, but one in which they must ultimately take into account these practical considerations.

### *10.5.3 Implementation Successes*

While there were many barriers to implementation, there were also reported successes and benefits to using Radix. These benefits were observed more informally by researchers conducting classroom visits on a small scale and were corroborated by teachers' own accounts in the open-ended questions of the surveys and during the interviews. The five broad categories of benefits teachers talked about include:

1. Pedagogy fit and approaches used
2. Curriculum alignment and content learned
3. Practices and soft skills developed
4. Level of student engagement
5. Unique qualities

As the data on each of these benefits is presented, bear in mind that many of the comments about the power of Radix were made by the same teachers who described the difficulties they had. Despite many of the barriers, it is often those same teachers who find ways around them in order to experiment with innovative pedagogies and facilitate deep learning for their students.

#### 10.5.3.1 Pedagogy Fit and Approaches Used

When teachers were surveyed about whether Radix was feasible to use, in addition to the negative responses presented in the previous section, there were also 11 specifically positive things mentioned, out of 29 total (38%). Interestingly, ten of these positive comments (91%) were related to pedagogies supported by Radix. This shows that pedagogy and not only content standards is important to teachers in their implementations. The top pedagogical approach mentioned was inquiry learning and opportunity for exploration. The other approaches that emerged as important were differentiation, the ability to have students progressing at different rates, and collaboration, opportunities for students to work together and help each other. All of these are approaches that are student-centered and not so common in the traditional classroom, so teachers were excited about a tool that created that type of environment. One teacher described differentiation and inquiry in her comment, saying that “It allows students to work at a speed and processing rate that is unique to them. In addition, it involves an inquiry approach that is conducive to engaging students in particular topics.”

Looking more specifically at collaboration, we saw that this was a pedagogy that teachers may not have expected to come out of Radix but that they were pleasantly surprised to see. When asked if they noticed their students collaborating while playing Radix, an overwhelming 27 out of 30 (90%) teachers responded yes. While the collaboration built into the game itself is somewhat limited, students stuck on particular tasks will often turn to their classmates for help and spark conversation that way. One teacher reported, “They truly helped each other! Yet, they were quite careful not to give away any secrets!! I found them to be quite competent when helping another student navigate.” It is interesting to note that while teachers commonly reported wishing they had more time to become familiar with the game themselves and more resources to help them learn the game, they also saw a lot of students helping each other which may have mitigated the challenges of problem areas within the game. Because of this as well as other benefits of peer-to-peer collaboration, it is a component that teachers see as important.

When asked more in depth about whether Radix fits with their current teaching methods and approach, 11 out of 14 (79%) teachers said that overall it fit well. For example, one teacher answered, “For me as a teacher, it fits in really well. I tend to emphasize the inquiry-based, I tend to emphasize the cooperative groupings. I don’t like to talk to them that much, which drives them crazy.” It is logical that most of the Radix teachers felt the game’s pedagogy fit well with theirs, because as shown previously, the teachers who were willing to participate also used Radix more, suggesting that they had reasons why they chose to use Radix. The fact that the majority of teachers appreciated the game’s approach supports the idea that pedagogy fit is an important factor in planning their curriculum.

#### 10.5.3.2 Curriculum Alignment and Content Learned

In addition to appropriate pedagogy, teachers also put a lot of importance on the curriculum and standards included in their game-based activities. When surveyed about how the Radix curriculum fits within their curricular objectives, 14 out of 34 (41%) respondents felt that it fit well, with another 13 (38%) describing ways in which it both fit and also with ways in which it didn’t fit. In addition, 8 out of 14 (57%) teachers that were interviewed described the Radix curriculum as an easy fit with their own class’s learning objectives. While these results are somewhat mixed showing that the specific content in Radix is not necessarily a good fit for everyone’s curriculum, they also show that having game content aligned to learning standards is something that teachers are looking for. The Radix curriculum was carefully designed to address this need, and many teachers noticed those specific areas of alignment in their classes. For example, “I thought it fit in really well with our new NGSS standards that we’re trying to cover, especially with body systems and genetics." And "I think that the topics are right, are aligned. … there were many topics that were the same kinds of things that they talk about in the school; so geometry, about heredity and traits."

Drilling down more specifically into what teachers think their students learned from playing Radix, 11 out of 28 (39%) specific responses described content knowledge. Teachers mentioned seeing learning gains as a result of a variety of uses such as priming, review, and enrichment. Some of these gains were seen on quizzes teachers gave and some in other areas like classroom discussion. Some saw students using Radix as a new way to explore curricular concepts, such as the teacher who reported, "I see some girls using it to model 3D scenarios for problems as species evolution and planning how change traits in this species." Other content areas were more similar to the traditional treatment of a topic but provided additional exposure, for example, one teacher said, "Specifically, my students' overall understanding of Punnett squares improved dramatically. I focused on the genetics unit to measure a before and after understanding of traits. Student scores went up across the board." Many of their observations were in relation to specific learning objectives or concepts such as these examples of species evolution and Punnett squares, demonstrating that when it comes to content learning, teachers do value alignment and observable learning results.

#### 10.5.3.3 Practices and Soft Skills Developed

In addition to content knowledge, however, there was a slightly more nuanced set of benefits that teachers also saw in their Radix implementations. When asked what they think their students learned from playing Radix, there were 7 out of 28 (25%) mentions of science or math practices and 10 (36%) mentions of soft skills. These kinds of learning can be more difficult to assess, but they can also be more powerful in the eyes of teachers who value them, and this was reflected in their responses. The practices they saw students developing include skills such as problem-solving, critical thinking, and engaging in the scientific method of hypothesis and testing. For example, one teacher noticed, "While there were many opportunities for students to learn terminology and concepts, there is no doubt that my students were learning how to become better problem solvers. This was evidenced in their discussions, questions, and elation when they overcame difficult obstacles." These are skills that apply to a range of topic areas but are especially important in STEM domains and can be tricky to teach in a traditional teacher-centered classroom. Similarly, soft skills were a category of skills that came up frequently with Radix teachers as well, and this includes things that can really only be learned experientially such as perseverance, managing frustrations, and independent thinking. One teacher listed a few things she noticed her students doing and learning through Radix: "There were many soft skills I saw embedded in the learning. Perseverance, sticking to a task for a long period of time, using resources to learn how to do something, read the directions." Another teacher put it very succinctly by saying, "I think for the most part, they learned that some things online are difficult, and you have to READ and THINK." This may seem obvious to many, but for students whose learning experiences are often very scripted and straightforward, having to synthesize information and figure things out in an online world can be transformative. While this type of learning may not be a key piece in all teachers' classrooms, for the type of teacher that is interested in game-based learning and large-scale or inquiry-based games specifically, choosing tools that can help develop practices and soft skills is likely to be a high priority.

#### 10.5.3.4 Level of Student Engagement

Another major area that emerged as an important benefit was student engagement. When asked how they think Radix supports student engagement, 21 out of 30 (70%) respondents felt that it supported engagement well, with another 5 (17%) describing ways in which it engaged some students but not all. As one teacher explained, "I think it's a great way for student to engage the material and other students. Students generally like playing games in class and it's a sly way of encouraging students to enjoy the learning process through an enjoyable activity." One interesting distinction that many teachers made was between students who were gamers and those who weren't. One teacher who observed this difference in her students said, "I think it is really good for students who have had bad experiences with traditional math. I saw those who had a good sense of how to play video games excelling at this. However, the students who have excelled at traditional math sometimes don't have video game skills and would shut down." This is an interesting trade-off for a teacher. On the one hand, they are excited by tools that can engage students that typically struggle. On the other hand, they need to be able to engage all students. This issue is complicated further by the fact that while sometimes teachers may interpret student behavior as not having video game skills, it could also be that they don't have the skills to explore an open-ended world when they are not provided with step-by-step instructions. Given that that type of traditional book learning usually does a mediocre (at best) job of engaging all students, the teachers who chose to continue with Radix likely weighed this trade-off in favor of using the game as a unique experience for their students and in good faith that over time students would learn to excel in an inquiry-based environment. In any intervention the teacher must consider both her own educational goals for the students as well as the current and potential perspectives of the students themselves, making engagement an important factor in the perceived success of a game-based unit.

#### 10.5.3.5 Unique Qualities

Teachers have a plethora of tools to choose from in their teaching, with more and more games being included in that menu of options. One theme that emerged was that teachers were excited about Radix as something new and different from what they usually have access to. So in the survey, we asked them specifically how they felt Radix was different from other game-based technologies they had used. Not surprisingly, 10 out of 29 (34%) specific responses were related to learning that occurred through the game, including standards, content knowledge, and skills. One teacher described how Radix teaches in a unique way by explaining that, "It's so different because it's within its own context...not like a quizlet or a Socrative with traditional review problems. I appreciate that the math is buried in the problems so that students really have to reason through it." Interestingly even more of the responses, 16 out of 29 (55%), were related to the game experience including things like the narrative, game world, and general feel of the game. For example, one teacher responded, "I think the Radix world and the characters and graphics were excellent regarding game based education technologies." Another teacher clearly described the way these two factors came together in her teaching, saying, "What is unique about Radix is that it provides a storyline that ties in a broader range of biology content so that I, as the teacher, can anchor class discussion and/or assessment in this broad story that everyone shares." These comments all demonstrate that teachers' interest was piqued by some of the unique aspects of Radix, which may play a big role in their perception of how these aspects can benefit their students.

## *10.5.4 Factors not Discussed by Teachers*

Based on teachers' surveys and interviews, we categorized the main themes into implementation challenges and implementation successes as discussed above. However, there were a few aspects that researchers and designers felt were conspicuously absent from the teachers' accounts of their implementations. These are curricular connections, formative assessment, and mismatched pedagogy. We believe these aspects deserve to be mentioned, as the fact that they were not a major discussion point is also quite telling.

### 10.5.4.1 Connections Across the Curriculum

Teachers were asked about how they implemented Radix, how they saw their students learning, how it fits with their curriculum, and other related questions, but there were only a few mentions of specific ways that teachers made connections between the game and their curriculum. Much of the value of preparation for future learning comes from the earlier experience which is then built upon in subsequent activities, but this transfer does not necessarily take place spontaneously. In order to be successful, teachers were encouraged to explicitly facilitate reflection and class discussion about things that had been observed in the game world and incorporate those examples into their lessons. This was rarely reported by teachers, and it was rarely observed as well. The reason for this may lie partly in the time constraints felt by most teachers – with class time taken up playing the game – there were few opportunities to fit in anything else game-related. However, it may also be due to a lack of understanding of how to best implement this pedagogical approach. Inquiry learning and other student-centered methods are new territory for many teachers and even if they are excited to practice them, it is a big leap to tailor your curriculum in ways that meaningfully support those pedagogies. Therefore, deep curricular connections may be seen as a barrier – something difficult and time-consuming to implement – or alternatively as a benefit, something that can bring about deep learning if used effectively. The fact that it wasn't at the front of most teachers' minds shows that it may have been a missed opportunity for teachers to reap more benefits from the Radix experience.

#### 10.5.4.2 Formative Assessment

We were surprised by the feedback (and lack thereof) on formative assessment. When asked whether they thought Radix could be an effective tool for formative assessment, the largest category of response, 9 out of 15 (60%), was that it would be if certain conditions were met. In many cases this condition was if the game could provide more data about what mistakes students were making or if teachers had more control over assigning smaller chunks of the game at a time. Other teachers felt it was useful for formative assessment but that it didn't fit in their implementations because of time limitations or because of where in the curricular unit they placed the game. One teacher echoed the sentiments of many others when she said, "I think it could. Again, and this would come more into some of the issues I came into with as a teacher, with the assignment of quests and having everything open, and kind of the confusion there." These responses show that while most teachers didn't actually use Radix as a formative assessment tool, the majority of them did think about how it could be used, suggesting that the assessment purposes of a game could be an important factor for consideration.

#### 10.5.4.3 Mismatched Pedagogy

When looking at both content and pedagogy fit, there were very few teachers who felt that Radix was not a good fit for their content standards and their existing approaches. On the contrary, most teachers who participated in the study were excited about the inquiry-based, exploratory nature of the game. They also had an easy time aligning the content areas with their school or district's standards. It is worth noting that this is not because Radix is a game that fits with everyone's content and pedagogy. Rather, it is almost certainly due to the fact that these aspects of Radix were emphasized in all outreach and communications about the game, so teachers knew when they signed up for the pilot that this was a tool they would be excited about. Teachers who were less comfortable with inquiry learning essentially were self-selected out of the study by not choosing to use the game in the first place. For this reason, the survey and interview responses don't represent teachers who are making a great shift in going from traditional to more progressive pedagogies. We mention this here because when thinking more generally about tensions teachers face in implementing game-based curriculum, in many cases the mismatch of pedagogies, or rather the need to bridge two teaching styles, will certainly play a large role in the teachers' experiences.

## 10.6 Discussion

Having examined teachers' perspectives on Radix in the previous sections, we are now better able to think about the question of why and how teachers choose to use Radix. One scenario is that teachers who choose to use the game have low barriers to entry, for example, their schools have accessible computer labs with reliable Internet, their curriculum is flexible enough that they can fit in time for game-based activities, and their students are engaged with and motivated by the gameplay. These are certainly all contributing factors to making Radix feasible to implement. Referring back to the decision-making process depicted in Fig. 10.1, these would be teachers that see Radix as falling on the low end of the barriers spectrum. However, we have seen that this is not necessarily the environment that most Radix teachers are working in. These barriers do exist for many teachers who still persevere, finding ways around them or ways to cope with them in order to include Radix in their curriculum.

Another scenario is that teachers who choose to use the game see more value in Radix than other teachers. These would be teachers who see Radix as falling on the high end of the benefit spectrum in Fig. 10.1. This could stem from a more developed understanding of inquiry learning and student-centered pedagogy, which enables some teachers to see what students gain from Radix beyond content knowledge. It could also be an effect of certain teachers' practices. Teachers that implement game-based curricula in certain ways, including making more connections and fostering collaboration, may see benefits for their students that are stronger than they are for teachers using more traditional methods. Among the teachers that were most effusive about the value of learning they saw in the game, we did tend to see more autonomy given to students and more effort spent on integrating the game with existing lessons. These practices lead to an environment more conducive to inquiry learning and therefore provide more evidence to the teacher of the game's benefits.

The third scenario is that teachers who choose to use the game are doing so because they prioritize the things that Radix does well. These could be teachers who would put Radix in the middle area of Fig. 10.1, as a game that has both barriers and benefits. But for them, working hard to overcome barriers and find effective implementation strategies feels well worth the effort. They may be conducting what is essentially a cost-benefit analysis in which they conclude that while large-scale games take more effort and practice to implement well, they help teach students higher-order thinking skills which are difficult to experience in other arenas. This motivates certain teachers to find solutions to technical issues and reach out for support with pedagogy, because they feel the trade-off is worth it in the end.

There are teachers who fit into each of these scenarios. The set of barriers and benefits that influence their decisions tend to have a lot of overlap, as we saw among our Radix teachers. What we should be cognizant of is that these factors interplay in different ways in different teachers' experiences. People have different levels of patience for technical issues and different levels of enthusiasm for inquiry learning. As a result, their decisions are based more on their own perspective of the factors involved than on any quantitative measure of infrastructure or skill. In reality, it is a combination of all of the above scenarios, together with individual personalities and preferences, that lead teachers to their ultimate decision about what to include in their lesson plans.

### *10.6.1 Increasing Adoption*

The next question that is important to ask is how to make Radix and other large-scale digital games more feasible overall for teachers to implement. We have seen that under certain circumstances, both students and teachers can really thrive in a game-based learning environment and that there is a lot to be gained from the experience. Therefore, making those experiences more accessible to teachers who are interested but unsure would benefit both teachers and students. For teachers in this category, accessibility could be improved by both decreasing barriers – making challenges seem less daunting – and increasing benefits, making learning gains more apparent. Developing strategies for both could help lead to greater adoption and more widespread game-based learning.

The best way we have seen to work toward both of these is through increased and targeted support for teachers who are starting to implement a game in their classroom. Much of this support can be provided through professional development activities. Setting expectations about challenges teachers may face, drawn from real-world schools, can help them understand where things will feel difficult. Similarly, setting expectations about the benefits they may see in their students, and the skills that may emerge over time if not right away, can help them visualize what they are working toward. Professional development (PD) resources can give teachers techniques to practice as well. In-person or video training sessions can show them how to step back and let their students take the reins within the game. It is also an opportunity to present methods for facilitating meaningful conversations that get students to reflect on their game experiences. These are some of the techniques used by teachers who experience strong benefits from Radix, but we cannot assume that all teachers naturally know how to use these approaches. For this reason, providing training on strategies that best complement the game experience can enable those learning gains to become more apparent. Along with these initial suggestions, though, must come a longer-term PD program designed to support teachers not only at the beginning of their implementation but throughout their own learning process.

Teachers may focus on more of the technical barriers early in the school year, before they are ready to try novel implementation approaches. And it may not be until quite late in the year that they can really take a step back and reflect on changes they are seeing in their students. For these reasons, quality and sustained PD opportunities are important to help teachers design effective implementations and recognize the benefits they can bring about for their students.

Another aspect of support that may help scaffold teachers' development of new approaches is to provide detailed bridge curriculum, along with specific examples of how other teachers have used it effectively. The iteration of Radix that was distributed during the pilot period contained teacher materials that included discussion questions for each quest line and suggestions about the types of connections that could be made. However, we feel that many teachers could have benefitted from more detailed and specific curriculum ideas. For example, a weeklong genetics lesson plan might include Radix gameplay, class discussion on breeding strategies, group work collating data collected in the game, and paper or lab activities demonstrating various inheritance patterns. Such resources could help teachers more clearly envision how to connect in-game experiences with out-of-game activities and scaffold the design of those lessons. This curriculum support is important for teachers who feel overwhelmed by game-based learning or new pedagogies in general.

Finally, to go along with both professional development and provided curriculum, teachers of all comfort levels could benefit greatly from a community of other practitioners teaching with Radix. Our pilot included some elements of this in an online forum space and biweekly webinars where teachers could connect and ask questions. Being able to compare experiences with other teachers grappling with the same challenges can be inspiring and grounding at the same time. Teachers would have a safe space to air their frustrations to peers who can relate. They would also have the chance to share their successes and get feedback on good ideas for supporting students in Radix. In addition to these practical purposes, building a community around a learning game experience can make teachers feel like they are part of something larger, a kind of movement to develop deeper learning tools and change the learning experience for their students. Of course this hinges on the assumption that teachers have time to participate in these communities, which as we know is a major barrier. But given the time, these are the ways in which an authentic community helps teachers figure out how to best implement the game and motivates them to persevere.

The goal of these teacher supports is to mitigate the barriers teachers face and draw out the benefits, thereby shifting the balance to a point where more teachers find game-based learning feasible and valuable. Based on the interview and survey data presented in this chapter, we can see that the extra effort necessary to thoughtfully implement a large-scale digital game like Radix pays off in the building of skills and practices that are often difficult to situate in a traditional classroom. In order to bring these opportunities to a greater number of teachers and students, we must work to emphasize the value of games in the classroom and develop the environment and supports necessary to implement them well. We hope that identifying some of these factors will lead to increased support surrounding rich learning games, greater adoption among teachers, and in turn deeper learning for more students.

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# Chapter 11
# Al-Kimia: How to Create a Video Game to Help High School Students Enjoy Chemistry

**Beatriz Legerén Lago**

**Abstract** This chapter describes the creation process of "Al-Kimia", a video game targeted at Spanish high school students that aims to generate positive attitudes towards Chemistry (and Science in general) amongst its players. It is hoped that this will provide a useful reference to guide the development of similar titles in the future.

Firstly, it explores the reasons why a video game was chosen as a resource to achieve educational objectives. Secondly, the effectiveness of game-based learning has been analysed, with references to the available literature.

One of the key sections of the chapter describes the process that was followed to define the structure of the video game. Hunicke's Triad (mechanics–dynamics–aesthetics), Schell's Elemental Tetrad (aesthetics–mechanics–technology–story) and Kiili's Experiential Gaming Model are theoretical frameworks that were reviewed. In order to meet the requirements of the project, a new hybrid framework for the design of educational video games was created.

A more detailed description of the project's development provides an example of how this theoretical framework was used in a real-world situation. The challenges that were faced by the team and the steps that were taken to overcome them are also described.

Finally, this chapter focuses on the research studies that have been designed to measure the impact of the game amongst its target audience, as well as the lessons learnt from the whole development process.

**Keywords** Custom-made game • Edutainment game for mobile devices • Game design process for educational games • Role-playing game • Action game • Graphical adventure • High school • Secondary education • Chemistry • Science

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## 11.1 What Is Al-Kimia?

"Al-Kimia" is a combination of role-playing + action + graphical adventure title that includes simulation elements (tests, games) for mobile devices[1]. Players get a chance to do real chemical experiments in a virtual world, acquiring real chemical knowledge in the process and understanding how these discoveries have had a real-world impact. This title aims to generate positive attitudes towards Chemistry (and Science in general) amongst its players.

"Al-Kimia" is a joint effort between the video game team of the Faculty of Social Sciences and Communication of the University of Vigo and members of the Faculty of Chemistry of the University of Santiago de Compostela. Both teams are based in Galicia, in the northwest of Spain. This project has received competitive funding from the Spanish Ministry of Economy and Competitiveness.

Traditional teaching methods in Spain approach Chemistry (and other scientific subjects, for that matter) in a dry and unengaging manner. This creates a barrier to entry that limits the appeal of Chemistry as a viable option for further study and professional development. In other words, Chemistry remains a relatively unknown subject, which is not highly valued within the general student population. Aware of this reality, Chemistry teachers in the University of Santiago de Compostela were interested in changing this negative perception but discovered a lack of resources aimed at presenting chemical concepts in an entertaining and engaging manner. Overcoming this lack of resources provided the starting point for "Al-Kimia". Its development has been guided by the constructivist theory of experiential learning.

## 11.2 Why Design a Video Game About Chemistry?

Video game players are normally considered to be male teenagers, but is this stereotype actually true?

According to the Spanish Video game Association (AEVI 2015), in 2014, there were 14 million video game players in Spain, 40% of the total population. Spain is the fourth largest video game market in Europe by number of players, behind France, Germany and the United Kingdom. Spanish gamers between 11 and 64 years of age spend an average of almost 6 h per week playing. Over 77% of 11–14-year-olds play video games, compared to 75% of 6–10-year-olds, 66% of 15–24-year-olds, 48% of 25–34-year-olds, 35% of 35–44-year-olds and 15% of 45–64-year-olds. Spanish women account for 46% of total gamers, compared to 44% in the United Kingdom.

In 2014, total revenues for the Spanish video game sector were 996 million euro; packaged games accounted for 755 million euro, whilst online games generated 241 million euro (AEVI 2015). The video game industry has consolidated its position as the leading form of audiovisual and interactive leisure in Spain.

[1] An Android version of the game can be downloaded from https://alkimiasite.wordpress.com/. The game will also be available in the Google Play and in the Apple Store.

Analysis of this data suggested that a video game could be an effective platform for reaching high school students and to have them engage with Chemistry in a different way. The next steps were to discover how video games could be used as learning tools, choosing the type of video game, defining the elements it should contain and, finally, how to adapt the basic scientific knowledge to create an engaging game.

## 11.3 Use of Games as an Effective Learning Tool

Students' interest in digital technologies would suggest that including them in the classroom could be an effective way of facilitating learning and engagement. But it's important to highlight that just using digital technology does not guarantee this; a deeper change in the teaching process is needed whereby the teacher's role evolves from being a "speaker" to becoming a guide and enabler of experiences.

One possible approach to using technology in the classroom can be the use of video games, as their use can help create a culture of learning that is better adapted to the interests of students (Prensky 2001 cited in Kiili 2005). In this case, games must motivate students through experiences created in the game world and, at the same time, offer them the chance to explore, develop hypotheses and build objects (Kiili 2005:14). On the other hand, video games enable students to discover new rules and ideas, rather than just memorising learning materials created by others, thus giving meaning to the concept of problem-based learning.

This way of learning connects with what has been called experiential learning. Dewey (1938 cited Chisholm et al. 2009) highlights the important role experiences have in the promotion of knowledge, as individuals learn when they find meaning in their interaction with their environment. Smith (2001 cited Romero Ariza 2010) claims that one of the defining characteristics of experiential learning is that it involves the individual in a direct interaction with that which is being studied, instead of merely contemplating or describing it. Esnaola (2009) suggests that the objective of school learning isn't that students memorize or understand content; they should be able to demonstrate their understanding by their actions, solving problems in increasingly complex contexts.

All of the above suggested that a video game could indeed be an effective resource to make students engage with a complex subject such as Chemistry.

## 11.4 What Type of Video Game Is Most Effective for Learning?

Not all video games are the same, so it is important to know which types are more suited to a learning-based scenario such as the one being discussed. As the video game industry has matured, it has begun to receive increasing attention from academia, giving rise to different types of video game classifications.

Games were initially classified based on the technical characteristics of the machines they were played on (i.e. 8-bit, 16-bit, 32-bit, etc.). They were later organised based on what players could do during the game, giving rise to genres such as action, fighting, platforms, role-playing and adventure games. As technology has evolved, new types of games have appeared, such as real-time strategy or massively multiplayer online games.

Different authors have recently focused on the subject of video game classification. Djaouti et al. (2007, 2008) suggest classifying video games based on their rules, having been inspired by the methodology that Vladimir Propp used to classify Russian fairy tales. Sánchez and Gómez (2014) prefer creating a unique and free taxonomy for video games, with no links to other media.

In the case of Al-Kimia, the concept of Game Gestalt seemed especially relevant. Defined by Craig Lindley (2003), Game Gestalt says that it's not necessary to know all the rules of a video game in order to play it, although some rules must have been consciously learnt; the key thing is to establish a pattern of interaction with the game system, so that it can be enjoyed without having to read complex instruction manuals.

Some of the types of games to which the concept of Game Gestalt can be applied are:

- Action games: shoot whilst being attacked, healing, repetitive actions.
- Role-playing games: assume the role of a character and develop it by completing different tests.
- Strategy games: organize armies, conquer domains and defeat enemies.

When designing Al-Kimia, it was important to define what players would have to do; where, how and when they would be able to do it; and what they would achieve by doing so.

Story was another important element that needed to be taken into account when designing the game. In this case, the challenge was to find a narrative structure that would allow the history of Chemistry to be told within the game.

Ever since Homer compiled ancient oral legends, almost everything can be classified as story or narrative. But in this case, we define narrative as an experience that's time-based, that has a protagonist that faces a conflict that must be resolved and which can change as the player makes choices between possible outcomes (Cassidy 2011:294). In other words, we are talking about an interactive fiction adventure.

In the case of Al-Kimia, it was considered important to be able to demonstrate some of the basic chemical processes in an explicit and clear way. To do this, the use of simulation became necessary. In this case, simulation is understood as "representing something or experimenting with a model that imitates certain aspects of reality" (Pérez Porto and Merino 2011).

In conclusion, in order to achieve the basic objective of Al-Kimia, it was decided that the game should be a combination of role-playing + action + graphical adventure title that included simulation elements (tests, games).

## 11.5 How to Design a Digital Game

Stereotypes exist about the design of video games in the same way as they exist about gamers themselves. It can be considered a technological activity, as it is computer-based; it can also be considered an artistic endeavour, because what appears on the screen is so important. But designing a video game is not an art; it is a craft, and, as such, it is necessary to know the tools that are used in the creation process.

When creating anything, it is important to know the different parts that will form it and how they will relate to each other. This is especially true when designing a video game: it must be technologically correct so that it works as expected; it must be visually attractive; it must be entertaining and playable; and, in the case of a title such as Al-Kimia, it must contain information that will stimulate learning.

Defining video games is outside the scope of this work and has already been addressed by authors such as Salen and Zimmerman (2003), Esposito (2005) and Frasca (2003), amongst others. The different approaches to video game research (ontological, methodological or field-based, as per Cardero et al. 2014) are also outside the scope of this paper and will not be addressed either. In the next pages, the focus will be on discovering and defining the different elements that form a video game.

Different researchers have attempted to define the structure of video games. In *Toward a Unified Theory of Digital Games*, Ralph and Monu (2015) argue that the main elements of a video game are technology, story and playability. Earlier, in "A Formal Approach to Game Design", Hunicke et al. (2004) suggested that the main components of games are mechanics, dynamics and aesthetics (see Fig. 11.1).

Mechanics are described as "the particular components of the game, at the level of data representation and algorithms". Dynamics describe "the run-time behaviour of the mechanics acting on player inputs and each other's outputs over time". Aesthetics describe "the desirable emotional responses evoked in the player, when she interacts with the game system" (Hunicke et al. 2004:2).

In the *Elemental Tetrad*, Schell (2008) defined aesthetics, mechanics, technology and story as the four basic components of a video game (see Fig. 11.2). In this case, Schell defines aesthetics as "how your game looks, sounds, smells, tastes and feels". Mechanics are "the procedures and rules" of the game. Technology refers to "any materials and interactions that make [the] game possible", whilst story is "the sequence of events that unfold in [the] game", either "linear and prescripted" or "branching and emergent".

Other authors have approached the theory of game design from the perspective of "serious games", which have been defined by Chen and Michael (2006) as "Games that do not have entertainment, enjoyment or fun as their primary purpose".

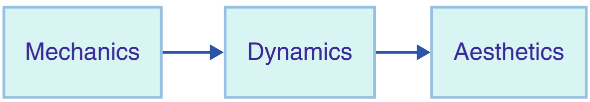


**Fig. 11.1** Mechanics, dynamics and aesthetics (Hunicke et al. 2004)

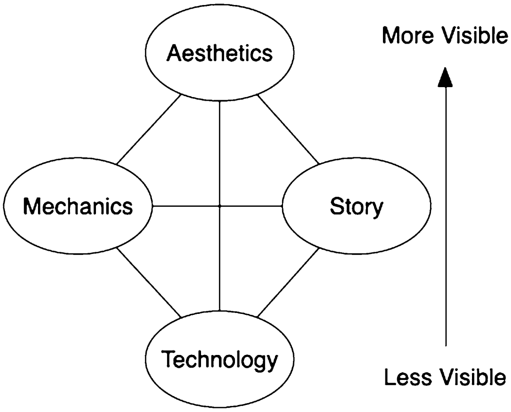


**Fig. 11.2** Elements that form a game (Adapted from Schell 2008)

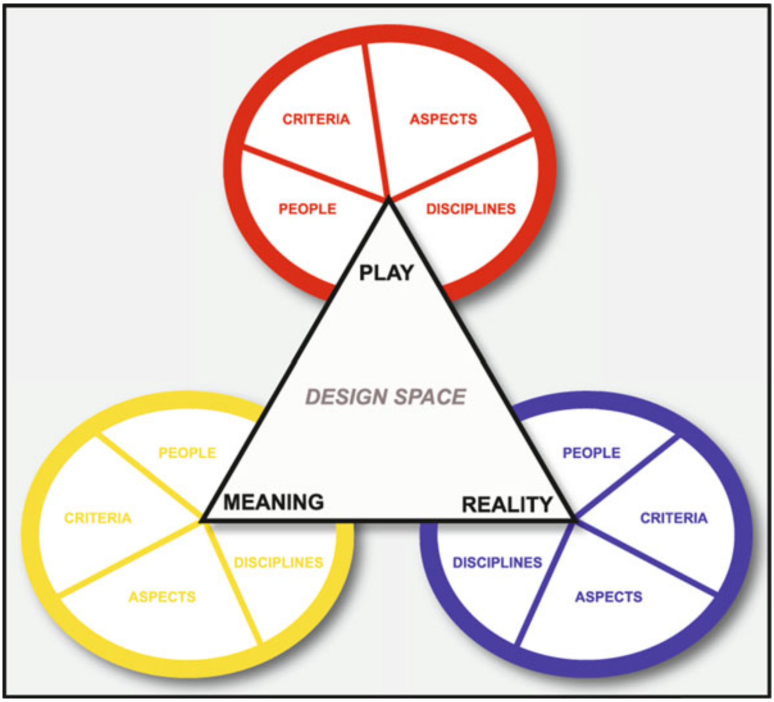


**Fig. 11.3** Triadic game design (Harteveld 2011)

Harteveld (2011) has proposed the Triadic Game Design model, which considers three main aspects in the design of a video game. Meaning refers to how players interpret the game; reality is where the game takes places; and play refers to the game playing experience (see Fig. 11.3).

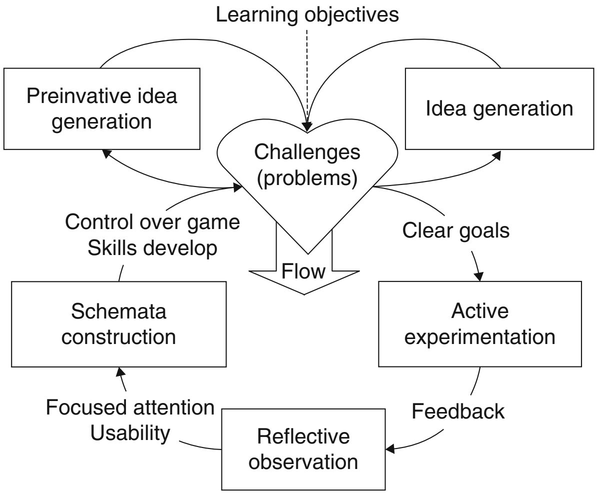


**Fig. 11.4** The experiential gaming model (Kiili 2005)

In the *experiential gaming model*, when analysing the design of games in education, Kiili (2005) argues that games present challenges to players that can be considered learning acts (see Fig. 11.4).

When designing Al-Kimia, all of the above models were reviewed in order to identify the one that would be best suited for the project. After careful consideration, however, it was felt that no single model would fit all the needs of the project, so a hybrid approach was chosen. The Experiential Gaming Model proposed by Kiili was used to define the core of the game, but elements of both Hunicke's and Schell's approaches were also taken into account. By combining these models, both the gaming and learning objectives were aligned to create an attractive and entertaining video game that would communicate its learning objectives effectively.

Figure 11.5 represents the different elements that were used to design Al-Kimia, an educational role-playing + action + graphical adventure video game.

Within this new approach, *mechanics* are considered to be the processes and rules of the game (Schell) that will help define its *dynamics*, which can be defined as the behaviour of the player (Hunicke); *aesthetics* refer both to the way the game looks and sounds (Schell) and to the player's emotional response when interacting with the game (Hunicke), whilst the *story* (Schell) will focus on the subject matter to be learnt, in this case the history of Chemistry.

The elements of the experiential learning process proposed by Kiili can be linked to each of the elements defined above. The *learning objectives* are developed within the story; the *challenges (problems)* that the player must overcome are linked to the mechanics, so that the dynamics they inspire will allow *active experimentation* by the player; the combination of these elements will enable the *construction of schemas* that, via the game's aesthetics, will create a state of *flow* in the player that will ensure that a learning experience takes place.

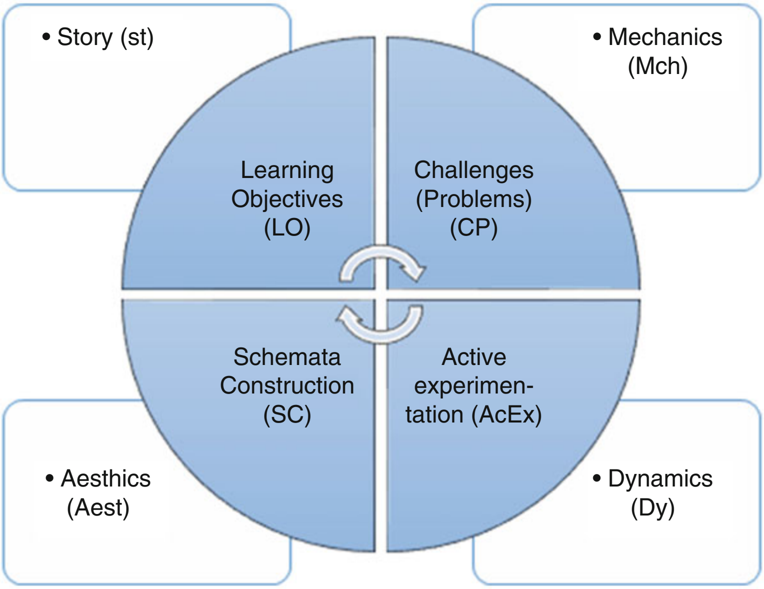


**Fig. 11.5** Framework for the design of an educational video game (Role-playing + action + graphical adventure)

## 11.6 Al-Kimia

Al-Kimia is a combination role-playing + action + graphical adventure title that includes simulation elements (tests/games) for mobile devices (smartphones and tablets).

**Role-playing** In role-playing games, players assume the roles of characters in a fictional setting. They take responsibility for acting out these roles within a narrative.

**Action** In an action game, players must use their speed, skill and reaction times to achieve their objectives.

**Adventure Game** The main characteristic of this type of games is that they are based on a narrative; players assume the role of one of its protagonists, and they must resolve different tests to advance and reach the conclusion of the narrative, like in a book or a movie.

According to Dillon (2004), some of the key characteristics of adventure games are:

- Game play is primarily driven by a narrative through which the player moves as the game progresses.
- The player generally controls the main character.

- Games are often based around quests or puzzles, which are solved through interaction with the game world and its objects – this is often integral to the game experience.
- Emphasis is on exploration, thought and problem-solving abilities.

In other words, they are games that invite players to explore the settings and objects within the game, with interesting and attractive characters. They keep engagement levels high by balancing a good story with giving the player choices to interact with it. They stimulate comprehension, observation and memory.

Al-Kimia is a combination of all of the above. Players will have to discover information to fill in the blanks in a mystery narrative. They will have to interact with other characters that represent famous chemists across the ages, and they will have to make the most of different objects they will find as the game progresses. They will also have to overcome tests based on real chemical experiments and defeat different enemies as they acquire new skills.

When designing a video game, choosing the right platform and format is the key. In this case, both the target audience (high school students) and the objective (making Chemistry more attractive) were taken into account to choose mobile devices (smartphones and tablets) as the ideal platform for this title. Players are able to play whenever they want, wherever they are. By structuring the game in different levels and allowing players to save their progress along the way, players aren't required to make a significant commitment to the game. Using this casual gaming approach broadens the pool of potential players.

### *11.6.1 The Story*

Enzo is a high school student that, after finding a blank ancient book amongst his great-uncle's belongings, is magically transported to different moments in time. He will have to perform different experiments, gaining basic chemical knowledge along the way. As he progresses through the game, his great-uncle's book will fill up with information about the main discoveries that have shaped Chemistry through the ages. But Enzo will also need to build up his other skills, as evil Zósimo and his gang will try to block his way and erase all scientific knowledge.

To achieve his objectives, Enzo will be able to use different items that will allow him to defend himself and to attack his enemies. Different mentors will guide him along the way, including Aristotle, Avicenna, Robert Boyle, Henning Brandt, Antoine Lavoisier, John Dalton, Joseph Proust, Alfred Nobel, Mendeleyev, Marie Curie and Niels Bohr.

The game has been structured in five main levels corresponding to a different moment in history: the Prehistory, Ancient Age, Middle Ages, Industrial Revolution and Contemporary Age. Each level is divided in several stages.

In Al-Kimia, all the objects, challenges and actions are linked to the scientific knowledge available at each moment in history. In order to advance in the game, players must acquire basic chemical knowledge and perform experiments that were crucial in the development of Chemistry as a scientific subject.

### *11.6.2 Applying the Theoretical Framework in the Real World*

The starting point of the game design process was the factual information provided by members of the Faculty of Chemistry of the University of Santiago de Compostela. The most important chemical discoveries across the ages were selected and situated within their historical context. Based on this content, the members of the video game team of the Faculty of Social Sciences and Communication of the University of Vigo designed the different elements of the game, as defined in the chosen theoretical framework.

Figure 11.6 illustrates how the different elements of the chosen game design framework were adapted to the specific requirements of the Al-Kimia project.

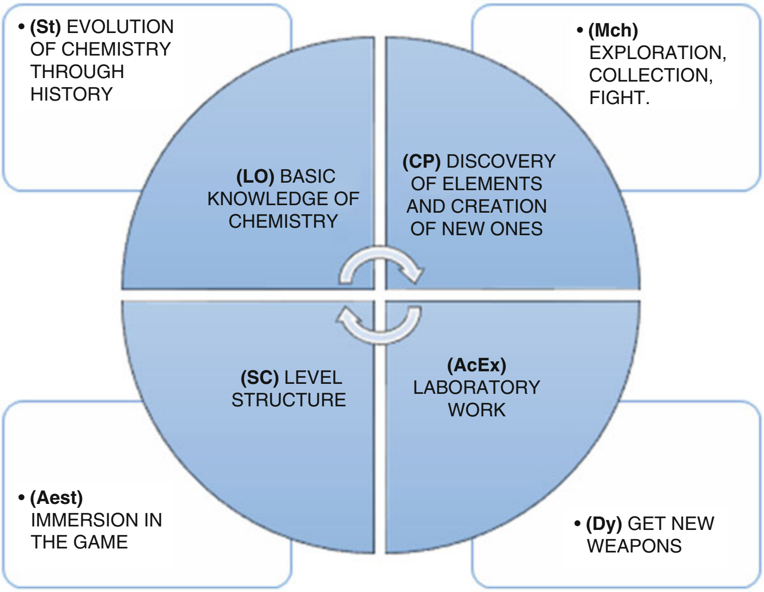


**Fig. 11.6** Adaptation of the framework for the design of an educational video game to Al-Kimia


**Fig. 11.7** Screenshot of Al-Kimia: Prehistory level

To further illustrate how the framework has been used in the game design process, a detailed description of the first level of the game is provided as an example. This level corresponds to prehistoric times (see Fig. 11.7).

**Learning Objectives (LO)** To discover the first chemical elements discovered in nature and how their combination enabled the human race to evolve

*The Story (St)* Will be based on the concepts to be explained and will provide information on how to achieve the objectives.

**Challenge (Problems) (CP)** How to find the chemical elements, combine them to create new ones and defeat the enemies. Players must create weapons with wood and fire, create protective clothing with the pelts of animals they have defeated, bake clay pots and, finally, discover the use of metals.

*Mechanics (Mch)* To progress in the game, players must undertake exploration, collection and fighting tests. As each level is solved, a new page appears in the book.

**Active Experimentation (AE)** Players will have to use their knowledge of the game and their skills to progress in the game.

*Dynamics (Dy)* The following tests need to be solved:

- A tree is burning. A stick needs to be collected and set alight. Fire has been discovered.
- Some clay needs to be collected. Players will be able to mould it into bowls using water from a nearby stream.
- Clay needs to be baked to harden the bowls which can also be used as weapons.

- Metal can be discovered in the river.
- Animals need to be defended against using new weapons.
- Animal pelts can be used as protective clothing.

**Schemata Construction (SC)** By actively experimenting, players will learn the basics of playing the game: how to use their avatar, how the game is structured, the way its economy works and what challenges need to be overcome. Most importantly, they have also started to learn about Chemistry and how it has helped the progress of the human race.

*Aesthetics (AE)* Players will use an avatar in a third-person, isometric view. Each level will consist of a single space that can be explored interactively. As players solve challenges, new things happen in the virtual space. This first level is set in nature to be consistent with the historical setting. It will consist of several fields, a river and a cave (where the use of colour and cave paintings will be introduced).

The objective is that, by combining all of the above elements, players will reach a state of *flow*.

## 11.7 Results

In order to evaluate the effectiveness of Al-Kimia in achieving its objectives, both pre- and postlaunch research studies were designed. A QUAN + qual design was chosen (Creswell 2009). The quantitative approach was given a higher priority in the study, whilst qualitative research was undertaken during the same data collection period.

In the prelaunch study, high school students from several schools in both rural and urban areas were required to complete an online questionnaire with closed-ended questions. Accidental sampling was used as the method to choose the sample of the study. Further information on the sample that was used in this study can be found in Table 11.1.

There are two objectives to these studies:

- Objective 1: to baseline current knowledge on Chemistry and how it relates to everyday life amongst the target population
- Objective 2: to measure the impact that playing Al-Kimia may have in changing this knowledge

**Table 11.1** Sample of the prelaunch study: schools and students

| Schools | Students (by Spanish school year) |
|---|---|
| Seven schools in urban areas (four in Santiago de Compostela and three in Vigo) | 14–15 years old (third year ESO), 299 |
| | 15–16 years old (fourth year ESO), 413 |
| Five schools in rural areas | 16–17 years old (first bachillerato), 203 |
| | 17–18 years old (second bachillerato), 162 |

The prelaunch survey included references to the following four dimensions:

- The relationship between Chemistry and people's health and emotions
- The relationship between Chemistry and everyday life (painting, building, medicine)
- The role of Chemistry in subjects like education and caring for the environment
- The effect of digital tools on the learning process

The data obtained in the prelaunch survey was captured and analysed using Microsoft Excel. The analysis of variance (ANOVA) was done using SPSS. No statistically significant variations were detected between the different schools that took part in the study, so the results were analysed globally.

Without going into too much detail, the results of this prelaunch study show that Chemistry is still a relatively unknown subject; it is perceived as important in health-related issues, but there isn't a clear understanding of how it affects everyday life. Finally, there is a positive perception amongst respondents about using digital tools as learning tools.

At the time of writing, shortly after the release of the game, the postlaunch study hasn't taken place yet. Apart from focusing on the dimensions of the prelaunch survey, it will include an additional dimension: the structure of the video game itself.

The expected responses will help determine whether this title has achieved its objective of changing attitudes towards Chemistry amongst Spanish high school students.

## 11.8 Conclusions

As has been mentioned above, designing video games is not an art; it is a craft. In the case of Al-Kimia, it has become evident that this craft becomes even more complicated if players are required to learn as well as being entertained. The challenge is double: to create a solid interactive entertainment title whilst providing a valid and rich learning experience. A balance between these two factors, entertainment and learning, must be achieved if the end result is to be successful. The use of the new, hybrid game design framework presented above ensures that these two factors are aligned.

It is still too early to know if the objectives of the game have been met, as the postlaunch research has not been completed at the time of writing. One result is clear, however: the process of designing this video game has enabled both Chemistry professors and video game designers to gain an understanding and appreciation of their counterparts' area of expertise. This has proven to be an enriching experience for everyone involved in the project and could give rise to further collaboration in the future.

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# Chapter 12
# Designing Virtual Worlds for Learning History: The Case Study of NetConnect Project

**Assunta Tavernise and Francesca Bertacchini**

**Abstract** The possibility of exploring archaeological sites from a distance, visualizing historical monuments that are ruined or no longer exist, as well as the manipulation of specific 3D historical finds from the learner's point of view (thanks to an avatar having an I-vision), can enhance students' contextualization of the abstract knowledge of the school subject "history". In this view, in the international project "Connecting European Culture through New Technology – NetConnect", promoted by Culture 2000 European programme, three 3D virtual worlds (VWs) were realized according to a technology-enhanced constructivist offer of historical contents. The VWs are the ancient Biskupin (Poland), Glauberg (Germany) and the site of Lokroi in Magna Graecia (Italy). This chapter aims at presenting some results of learning linked to these three virtual worlds.

**Keywords** Learning • Education • Virtual world • Cultural heritage • Learning of history • Design of technology-enhanced settings • Educational paths • Teaching-learning methods

## 12.1 Background

In recent years, a growing field of studies has suggested that a learning focus on spatial thinking skills can support achievements in learning some specific subjects, because the attention to numbers and letters in a universe as flat as the page of a book represses the natural human skill of 3D thinking (Newcombe and Shipley 2015). Hence, several studies in multimedia and web technology have given rise to different kinds of educational virtual worlds (VWs), where learners can think and act as in the real physical world, manipulating 3D virtual objects. In fact, in accordance with the instructional principles derived from Piaget (1971) and Vygotskij (1974), learning is the result of a process of construction of knowledge based on a hands-on approach; the reference theory is constructivism (Kafai and

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Resnick 1996) that promotes the manipulation (also virtual) of objects for the increment of retention, involvement and a positive sense of success (Um et al. 2011; Verhagen et al. 2011; Bertacchini et al. 2013a, b; Bertacchini et al. 2012a). Moreover, 3D virtual exploration offers the important chance to carry on immersive experiences through personalized activities supporting learners' interests (Kuznik 2009; de Freitas and Neumann 2009; Ferguson 2011). In this view, the learning approach mixing "education" and "entertainment" has been called "edutainment" (Bilotta et al. 2009).

The implemented 3D environments have been mainly "serious video games" (Frye 2012; Connolly et al. 2012; Mayer 2012), where learners are actively engaged in the process of skill development (Merchant et al. 2014; Bertacchini et al. 2013a, b). However, in general, VWs have demonstrated a great potential for learning and teaching practices, as well as for the reaching of a wider public (Bertacchini et al. 2012a, b; Hughes 2012; Verhagen et al. 2012; Adamo et al. 2010; Beomkyu and Baek 2011). Regarding VWs based on historical subjects, virtually environments linked to cultural heritage have been dedicated to the faithful reconstruction of historical finds using 3D digitalization and scanning techniques. In fact, a great deal of research has been driven to an increasing effort in the realization of cultural VWs primarily dedicated to the archaeological site modelling. Furthermore, the use of three-dimensional computer modelling to virtually reconstruct monuments, buildings and finds refers to the concept of "virtual heritage" (Roussou 2002; Styliadis et al. 2009). A number of video games have also been realized, but their potential as learning tools is still under consideration. In order to support and promote knowledge transfer related to historical periods, the main consequence of these studies has been that learning has begun to be thought not depending on static 2D images, but it has started to be based on the exploration and manipulation of historical reconstructions (Bertacchini and Tavernise 2016). In these virtual worlds, visitors are not only allowed to witness history and cultural expansion through 3D objects, but they have access to a hands-on approach, attracted by technology (Kafai 2006; Mason and McCarthy 2006). Hence, in the view of supporting the learning of history, three immersive VWs have been realized in the project called "Connecting European Culture through New Technology – NetConnect", promoted by Culture 2000 European programme. These historical VWs can be enjoyed also by mobiles and iPads (Cutri et al. 2008; Naccarato et al. 2011; Linaza et al. 2008).

## 12.2 Main Aim of the Chapter

This chapter illustrates how the three immersive NetConnect VWs have been designed in order to offer a technology-enhanced constructivist setting endowed with virtual manipulation (Gärdenfors and Johansson 2005), as well as the results of two researches on learning. In the first one, 208 users (Biskupin 127, Glauberg 43, Lokri 38), aged between 12 and 30, have evaluated the VWs answering to an ad hoc-built questionnaire including the following sections: ergonomic factors (comfort during the system use), human factors (human-computer interaction, HCI), content (quality of the contents/animations and interactivity) and suitability for the task (appropriateness for learning).

In the second research, 50 Italian subjects from 15 to 18 (secondary school students) have studied the topic “Magno-Greek colonialism in Italy” using the VW “Lokroi”, developed in NetConnect project. In particular, the learning was measured in a 12-hour laboratory course through a quantitative entry and post-questionnaire; then, 24 items from the Intrinsic Motivation Inventory (IMI), a seven-point Likert scale, were used to assess students’ motivation. Finally, descents’ opinions on positive/negative aspects of the experience were collected.

## 12.3 NetConnect Virtual Worlds

### *12.3.1 Historical Details and 3D Reconstruction*

Three immersive VWs have been realized in NetConnect project: the reconstruction of ancient Biskupin in Poland, Glauberg in Germany, and the site of Lokroi in Magna Graecia (Italy) (Fig. 12.1). They represent the important result of the collaboration of an international team consisting of archaeologists, psychologists, modellers and computer scientists (Bertacchini et al. 2007). The expertise coming from various disciplines and five different European countries has also been integrated: Italy (Evolutionary Systems Group (ESG) of the University of Calabria and the Centre for Advanced Computer Graphics Technologies (GraphiTech)), Germany (Fraunhofer Institute for Computer Graphics and Roman-Germanic Commission), Spain (Visual Communication and Interaction Technologies Centre (VICOMTech)), Poland (Institute of Archaeology of Warsaw University) and the United Kingdom (Glasgow School of Art). In the project, an interactive version of three virtual archaeological sites has been distributed through DVDs to schools and divulgated through a web-based version.

In these VWs, visitors have an active role thanks to the possibility of following different levels of educational paths (Tavernise 2012; Tavernise and Bertacchini 2016), including the manipulation of different 3D objects. In fact, they can look for cultural heritage artefacts on the basis of their archaeological characteristics, recognizing and manipulating them in a 3D setting (Bertacchini et al. 2012b) (Fig. 12.2).

This manipulative construction of knowledge cannot be replicated in the physical world, because the finds could be partial or fragmented and certainly stored in a museum. Moreover, regarding buildings, users can learn their temporal set, spatial relations (e.g. the specific and related position in the city) and use (e.g. the building called Stoà was used by pilgrims). In a specific path, the interchangeable view of the virtual object or building, as well as the circumstance of the real one, increase learning.

**Fig. 12.1** Scenes from the three NetConnect virtual worlds: Glauberg, Biskupin, and the multimedia section of Lokroi (NetConnect project, 2009)

Regarding historical details, daily life scenarios are reconstructed on the basis of a detailed ancient documentation. In fact, the reconstruction of Lokroi scenes is based on those represented on Magno-Greek vases and votive tablets in terracotta called Pinakes, dated back to the period between 490 and the 460 BC. For example, the scene of the tuna seller in the market square is modelled on the basis of an ancient vase stored in a window of the "Mandralisca Museum" in Cefalù (Sicily, Italy) (Bertacchini and Tavernise 2012). The 3D modelling of specific farmyard animals and pets originates from their presence in Pinakes, and the chosen vegetation is typical in Southern Italy (scholars affirm olive trees were present in the selected historical age).

Regarding navigation in VWs, users can use a map clickable on the right side of the screen or a menu situating user's point of view in some selected places of interest. Visitors can also explore the city (virtually) walking in the streets: big red arrows show interesting buildings, and the avatar can move as a character in a video game to reach them (i.e. jump and run). Finally, in order to enhance history learning, users can access videos, pictures and texts in a multimedia section (Chowaniec and Tavernise 2012).


**Fig. 12.2** An example of 3D objects that it is possible to manipulate in Lokroi VW (NetConnect project, 2009)

### *12.3.2 Design, Edutainment and Gaming Features*

NetConnect design involves standard desktop set-ups instead of immersive and expensive virtual environments, encouraging low-cost robust approaches, more suitable for large number of visitors as in the case of archaeological sites (Bertacchini et al. 2007). Such navigable environments have a long technological tradition, based on the diffusion of multiplayer games and virtual communities, and the activities for their realization were the following:

- Selection of archaeological and historical materials devoted to be an integral part of scenarios (e.g. buildings and cultural finds)
- Definition of educational paths to insert in VWs
- Multimedia analysis and choice of unity platform
- Design of the immersive environments
- Implementation and experimentation
- Creation of an international network among educational institutions in order to divulgate VWs

Agents consist of a small quantity of polygons (less than 2000), and their details are due to textures at a resolution of 1024x1024 pixels applied to the mesh with UV maps (Bilotta et al. 2011).

Regarding gaming features, the exploration of the environment follows an approach very similar to video games (e.g. visitors can go through a door only if they open it), and actions can be performed using the mouse, the keyboard, a joystick or a Wii™ wireless controller based on gestures. However, user's surrogate persona is not showed in the VW (there is not an avatar acting for the user, substituted by an "I-vision"), and it cannot interact with "atmosphere agents" populating the immersive environment (Bilotta et al. 2011; Corvello et al. 2011).

Finally, NetConnect VWs can be considered edutainment environments because they incorporate entertaining/instructional activities linked to history learning; from a didactic point of view, these 3D environments provide the possibility to virtually access educational contents in an easy and appealing way, by focusing on a comfortable user-computer interaction and the incorporation of information about the culture and the society of ancient periods in the technology-enhanced product. Moreover, users can select different digital materials as texts, pictures, audios, multimedia files and videos on cultural heritage reconstructions. As a consequence, visitors' exploration can be considered as an advanced learning opportunity.

## 12.4 Research 1: Evaluation of the Virtual Worlds

### *12.4.1 Research Participants and Questionnaires*

Research took place in three different countries (Poland, Germany and Italy). In particular, 208 participants, aged between 12 and 30, evaluated NetConnect VWs: 127 for Poland, evaluating the VW "Biskupin"; 43 for Germany, navigating the VW "Glauberg"; and 38 for Italian "Magna Graecia", exploring ancient "Lokroi". Materials included a personal computer with the VW and an ad hoc-built questionnaire (a five-point Likert scale with 1 being "disagree" and 5 being "agree"). The questionnaire included the following sections: user's personal profile (age, gender, education and familiarity with computers, 3D graphics and video games), ergonomic factors (comfort during the system use), human factors (human-computer interaction, HCI), content (quality of the contents/animations and interactivity) and suitability for the task (appropriateness for learning). The section on ergonomics was composed by three questions (e.g. "I feel high comfort during the system use") and that on HCI by six questions (e.g. "The interface is highly user-friendly"). Contents and appropriateness for learning were evaluated by five and four questions (e.g. "The animations are highly realistic", and "The presentation of the information on the screen supports me in performing my task"). The last part of the questionnaire was devoted to comments on the experience.

### 12.4.2 Procedure

Research had the following four steps:

1. Subjects' compilation of personal data
2. Navigation in NetConnect VWs without time limit
3. Compilation of an online questionnaire
4. Analysis of results

### 12.4.3 Results

Regarding ergonomic factors (comfort during the system use) and human factors (human-computer interaction, HCI), the 90% of the sample felt high comfort, estimating the navigation as highly intuitive. Only in two scenarios (Biskupin and Lokroi), the test of the Wii use was carried out, and the 52% of Polish users, as well as the 39% of Italian ones, agreed that the Wii use provided a high comfort possibility. However, regarding content (quality of the contents/animations and interactivity), only the 27% of participants declared to be satisfied (Bertacchini and Tavernise 2014). The majority of users affirmed to be enthusiastic on the possibility to have NetConnect worlds as support for learning, and, in general, comments remarked a positive instructional experience.

Regarding negative remarks, they were used for improving the system: bugs and errors were fixed.

### 12.4.4 Limitations and Future Works

Evaluation results showed a low satisfaction regarding 3D contents, maybe due to users' common use of advanced video games. Future developments will involve students' video recording during the system use for the realization of an interaction taxonomy. In particular, the communicative value of the various applications and the different charge of the different environments/contents in a single scenario could be measured. Results could be correlated with studies on manipulation and non-verbal communication in the learning of different subjects (Bilotta et al. 2007, 2008). New "virtual tours" in other historical cities could be designed and realized, guaranteeing a stimulating journey in ancient daily life. Moreover, this embodiment of information about the culture and the society of the period, also through the display of ad hoc-built contents, could be connected thanks to additional educational paths, developing a net of information like in a hypertext (Bertacchini and Tavernise 2014; Pantano and Tavernise 2009, 2011).

VWs could also provide the opportunity to "corrupt" the world, changing its shape according to the preferences of the "prosumer", a term that indicates consumer and producer coalescing into the same person (Febbraro et al. 2008; Tychsen et al. 2008). In this context, a huge quantity of active users ("prosumers") could produce and enjoy the contents according to the technological paradigm of Web 2.0. Further improvements could also involve on-site experimentations.

## 12.5 Research 2: Learning Through VWs and Motivation

### *12.5.1 Research Participants*

The experimental sample consisted of 50 Italian secondary school students aged between 15 and 18; 25 subjects were male and 25 were female. Participants' ethnical provenience (all the subjects were Caucasian and Italian) and demographic make-up (socioeconomic characteristics) were homogeneous. All students had an equal school curriculum, guaranteed by the school educational plan, called "Three-year Plan for the Formative Offer – PTOF".

The sample included students from six classes of the same secondary school, randomly assigned. As entry requests of information on familiarity with computers confirmed, all participants were comfortable with computers, already used in other instructional activities.

### *12.5.2 Procedure*

Research had the following six steps:

1. Collection of participants' data using an entry questionnaire (age, sex and familiarity with computers)
2. Assessment of the entry level of knowledge on Magno-Greek history through a learning questionnaire consisting of 15 multiple-choice questions (pretest): 1 point was attributed for each correct answer and 0 for each incorrect one, for a maximum of 15 points
3. Navigation in NetConnect VWs without time limit
4. Assessment of the acquired level of knowledge on Magno-Greek history through a learning questionnaire consisting of 15 multiple-choice questions (post-test)
5. Compilation of a motivation questionnaire (the Intrinsic Motivation Inventory, IMI), reported as reliable and valid by McAuley, Duncan and Tammen (1987), and analysis of results
6. Qualitative evaluation of the learning experience (Iqbala et al. 2010; Thompson 2011)

Regarding the fifth step, IMI consisted in a seven-point Likert scale (with 1 being not all true and 7 being very true), and, in this research, only twentyfour items were used in order to measure students' interest/enjoyment, perceived competence, effort/importance and value/usefulness. Their Cronbach's alpha values for the sample were the following: interest/enjoyment (seven items =a = 0.87), perceived competence (five items =a = 0.81), effort/importance (five items =a = 0.85) and value/usefulness (seven items =a = 0.77). IMI as a whole had an alpha value of 0.82 (Bertacchini and Tavernise 2016).

### *12.5.3 Results*

Regarding knowledge, Greek history is a topic of Italian secondary school curriculum, but Magno-Greek colonialism in specific areas is a subject almost unknown among students: this is confirmed by pretest results. However, correct responses increased significantly from pretest to post-test: the mean score 1.36 out of 15 (SD = 1.08) (pretest) became 13.38 out of 15 (SD = 1.18) (post-test), and a Wilcoxon matched-pair signed-rank test showed that the scores after the visit to the virtual world were significantly higher than the scores of the pretest ($Z = -2.054$, $p < 0.001$) (Bertacchini and Tavernise 2016). Hence, results suggest that the realized virtual world can be an effective support in the study of an unfamiliar subject.

Regarding motivation, the relationship between the scores obtained in the post-test knowledge questionnaire and those attained in the motivation test, in relation with the pretest, was investigated using a multiple regression analysis. In particular, a significant $R^2$ of 0.65, $F(2, 28) = 22.5$, $p < 0.01$, was found, and the subscale "interest/enjoyment" resulted as the strongest predictor (Bertacchini and Tavernise 2016). Results are in line with the outcomes obtained by Verhagen et al. (2012).

Regarding qualitative analysis on the positive and negative aspects of the learning experience using NetConnect VWs, students' comments were extremely positive. The major part of learners commented the feeling of play as the best part of the assignment, while the tests after the navigation were considered as boring. Moreover, the majority of students suggested the use of computer and VWs for studying other school curriculum subjects.

### *12.5.4 Limitations and Future Works*

Since the majority of virtual worlds connected to history learning are simple 3D reconstructions of archaeological sites, without the possibility of 3D manipulation, an adequate comparison with other studies cannot be reported here. Furthermore, the examined data are partial with respect to a more complex research, in which all the three NetConnect VWs are involved. However, data collected in secondary school could be compared with additional data collected in primary school laboratory, as well as in courses with a synchronous version with multiple users' presence.

## 12.6 Conclusions

NetConnect scenarios represent an advanced learning opportunity related to the learning of history, because learners are not only allowed to look back into time witnessing history, but they also have access to an effective hands-on approach able to support a deep understanding. In particular, NetConnect VWs give the opportunity of exploring and manipulating within the 3D environments, allowing users' picking up of objects and investigation. Furthermore, the immersion in a 3D environment as an avatar with an I-vision allows engaging learning experiences.

This chapter highlights the use of 3D technologies that can support the learning of history by secondary school students, thanks to the creation of the global vision of a fragmentary archaeological cultural heritage and the motivating possibility to play with the virtual finds as in a video game. Moreover, regarding the efficacy of NetConnect VWs as user-friendly environments, they were evaluated by more than two hundred students that have affirmed that the use of the system is easy and that the 3D contents are enjoyable and of high quality. Negative remarks by users were not considered as limitations but as suggestions for further improvements: they allowed the fixing of bugs and errors in the system and, as a consequence, the enhancement of the project results. However, outcomes will be improved by new data coming from forthcoming experimentations.

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# Part V
# Serious Games for Children and Adolescents

# Chapter 13
# Intelligent Behaviors of Virtual Characters in Serious Games for Child Safety Education

**Tingting Liu, Minhua Ma, Zhen Liu, Gerard Jounghyun Kim, Cuijuan Liu, and Qintao Geng**

**Abstract** The child safety education is a very urgent task in China. It is necessary to teach children to recognize unsafe factors and learn how to escape from a dangerous situation. According to the psychological characteristics of children and constructivist learning theory, 3D serious game is an effective tool to assist child safety education in primary and secondary schools. In this chapter, we summarized some of our explorations in this field. We proposed a concept of the danger zone to simulate users' risk-taking behavior, introduced Non-Player Character (NPC) to increase user engagement, and developed a cognitive model that could simulate the intelligent behavior of virtual agents. We also tested cases of escaping from waterside area and earthquake. Results showed that children enjoyed this new safety educational method. By playing the game, they will learn what a danger zone is and how to escape from the danger zone effectively.

**Keywords** Child safety • 3D • Serious game • Safety education • Virtual character

## 13.1 Introduction

Currently, there are nearly 220 million children under the age of 14 in China. The science education is essential to the healthy development of children (Piaget and Inhelder 1969; Leslie et al. 1995). An important aspect of science education for

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children is safety education, which is not only for children but also for their parents. For a long time, both children and their parents pay little attention to the safety. Unintentional injuries among children happen very often and remain high in China. With the continuous expansion of social living space, the potential risk of child unintentional injuries is rising and the types of injury are increasing. According to statistics provided by Traffic Management Bureau, Ministry of Public Security of China, there are more than 18500 children under the age of 14 who died in road traffic accidents every year. The death rate is 2.5 times of Europe and 2.6 times of the United States. In traffic accidents, more than three-quarters of children are injured on the road.

In primary and secondary school, most students receive their safety education by learning regulations and accident cases through safety training videos. This inculcation education only tells children what not to do, without teaching them how to deal with the specific case. It is difficult to attract children's interest. Moreover, most of the existing child safety education books, even multimedia educational materials, are still using the traditional education mode, without any interaction. Take traffic safety education as an example; it is difficult for children to have direct perception of safety through the traffic rules. They prefer visualization method as their logical thinking ability is not yet fully developed. Psychologist Piaget (Piaget and Inhelder 1969) explained this phenomenon, as children's knowledge mainly comes from the cognitive construction of the objective world (Leslie et al. 1995). Therefore, setting up a learning situation is very important to increase learners' interest. We can get rid of cramming education model by a specific scene to help children construct specific safety knowledge. We used to demonstrate safety topics with 2D interactive animations (Liu 2006), but it is not an ideal way to provide a sense of immersion. Interactive 3D animation utilizes cartoon creations to visualize event's consequence with interactive computer animation technology. With the rising of cost-performance ratio of computer hardware, interactive 3D animation and games become widely adopted in education. Vivid teaching software could be developed with interactive 3D animation. In comparison with 2D animation technology, interactive 3D animation and games can effectively enhance the user's sense of immersion and help the user achieve learning outcomes.

Previous games on earthquake are mainly flash-based with trivial game mechanics such as running and rebuilding after disasters. We designed a few serious games for child emergency escape education. In these games, we adopted cognitive models in character design to simulate their behavior. We developed a rural waterside safety educational game and an earthquake escape game for children to improve their recognition skills about unsafe factors. Evaluation showed that these serious games raised children's safety awareness and had great potential in child safety education.

## 13.2 Current Serious Games for Safety Education

Serious games with highly realistic scenes have been used as adjuvant psychological therapy, fire escape training, and military training (Smith and Ericson 2009; Luo et al. 2014). For example, Padgett et al. (2006) developed a virtual reality computer game to teach fire safety skills to children diagnosed with fetal alcohol syndrome. Smith and Ericson (2009) helped children to learn fire safety skills with a less interactive game.

Building Information Modeling (BIM) was used in a fire escape serious game (Ruppel and Schatz 2011) to represent an accurate architectural 3D space for escape. The development trends for serious games include having more intelligent NPCs and more realistic 3D scenes, effective use of BIM, and utilizing various methods of physically based simulation, fluid simulation, collision response, and other effects in real time. A serious game can be a visual assistant tool for emergency training. With the popularity of head-mounted display (HMD), serious game scenes become more immersive and realistic. Chittaro and Buttussi (2015)) developed a HMD-based prototype of a serious game to simulate how passengers react to hijackers in the airplane. As users' experience could be enhanced by the realistic scene, this game can be used in the education to prevent terrorism. Jaziar et al. (2015)) used serious game to carry out fire evacuation education. Users could experience the evacuation at different conditions (flame, smoke, and temperature). Luca and Riccardo (2015)) designed a serious game for terrorist attacks that occurred in a train station to investigate mass psychology in emergency.

Serious game development requires an interdisciplinary endeavor. Psychology and artificial intelligence are becoming new selling proposition of serious games (Ma et al. 2011). It is realized that one of the technological innovations of next-gen games would be modeling emotions (Liu and Pan 2005). However, only a few games have done this, e.g., "The Sims" is a game that simulates mental activities for characters. Designers used hungry, physical strength, comfort, health, and other human variables to describe emotions of characters. The game referred to the big five personality traits from its psychology model. If the characters are in a bad mood, they would refuse the player's command and express their emotions. The personalized interaction between characters in the virtual society increased the interest of the game. The success of "The Sims" indicates that creating virtual characters with rich emotion expressions will be a core technology for animations and games.

## 13.3 Risk-Taking Behaviors and Danger Zone

Human behaviors are closely related to the environment. Thus, risk-taking behaviors generally occurred in a danger zone. We collected all kinds of children's accidental injury cases in recent years. By analyzing these cases, we found that majority of accidental injuries occurred due to poor knowledge, ignorance, or lack of safety awareness. This paper presents the concept of the danger zone, which refers to the specific area in children's living space. Once children enter these areas, their behaviors can easily cause harmful events with objects in the danger zone. The reason children's accidents happen frequently is that people lack sufficient knowledge of the danger zone. Some danger zones do not constitute dangers for adults but will cause fatal injuries for children. For example, on 4 October 2010, in Jiangbei District, Ningbo, China, a 2-year-old boy, who has just learned to walk, wanted to wee in his potty when adults were away. Unfortunately, he slipped when opening the lid of the potty and stuck his little head in the potty. Finally, firefighters had to come to rescue. In this case, parents may not realize that the potty would get stick in a child's head. If so, they would have taken precaution to prevent the accident.

The danger zone should be considered in child safety serious games to achieve the learning outcomes. Children should be allowed to explore and learn from mistakes in a safe environment. By constructing different security virtual scenes, children can roam in a 3D virtual space and control avatar's behavior in these scenarios. Different accidents can be simulated in the game environment. These virtual experiences of accident scenes and animation effects will effectively stimulate students' interest to obtain knowledge about the safety precautions (Figs. 13.1 and 13.2). For example, a dropped wire near the pole usually puts children at risk of electric shock. In order to help children identify these hazardous areas and risk-taking behaviors, serious game can simulate similar scenarios and corresponding results. Figure 13.1 shows a scenario about a dropped wire. Once the virtual character approaches the wire, the game will remind children about the risk of electric shock. If the user insists on touching the wire, he will see the horrible consequence on the screen. In the trial we found that children liked to venture in the virtual scene and were impressed with the virtual experience of accidental injuries. Our evaluation confirmed the feasibility of using 3D games to support child safety education.

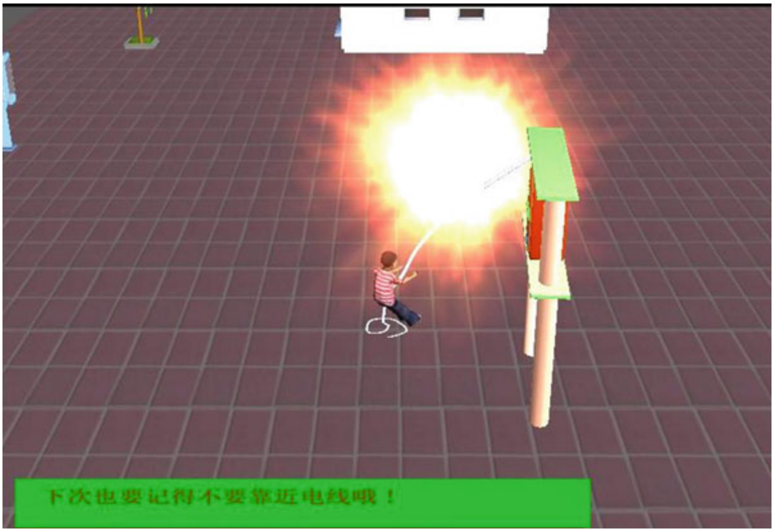


**Fig. 13.1** Danger zone around a dropped wire. The consequences are displayed if a child touches the wire

**Fig. 13.2** The danger zone grows in fire. The player needs to put out the fire with a fire extinguisher before passing through

We will take road safety as an example to explain our game design. In this security theme, user can control the direction and status of child's movement by keyboard and mouse. The danger zone is set on a road; if the child deliberately delayed the time to cross the road (i.e., lingering around in the middle of the road when the traffic light turns green), a virtual traffic accident would occur (see Figs. 13.3a and 13.3b). The player can repeatedly experience the scene to find out a correct way to cross the road. Objects do not need to be presented at their actual size in the game. According to the educational needs of the theme, important traffic symbols can be presented with different colors and exaggerated shapes.

## 13.4 Behavior Design for Virtual Characters

We found some children preferred to take adventures while playing the safety educational game. They would intentional break traffic rules and take a variety of dangerous actions. To prevent these actions, non-player characters (NPCs) were introduced in the game. These NPCs would warn the player of dangerous actions with prompt messages (see Figs. 13.4a and 13.4b).

In order to enhance the game's experience, NPCs should have believable behaviors. A cognitive model is established for the NPC's perception and behavior (Liu Zhen et al. 2011). It is used to guide NPC's autonomous behavior. The NPC's

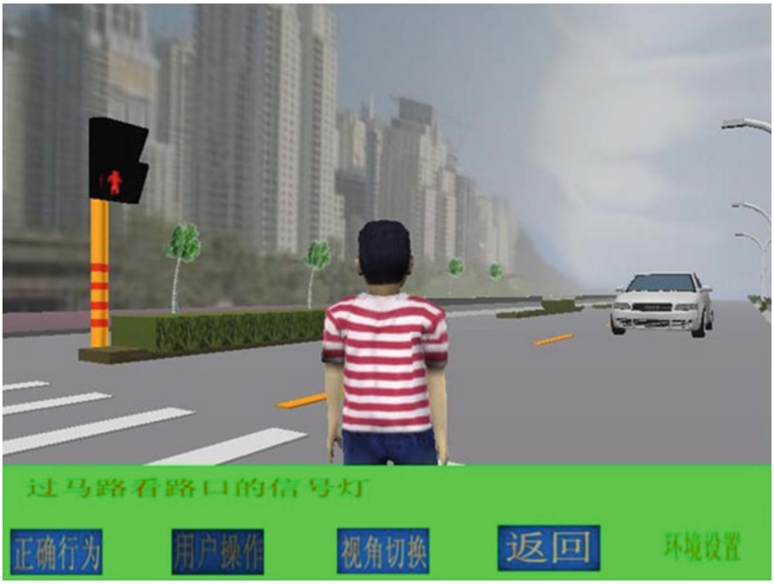


**Fig. 13.3a** A child does not move and stands in the middle of the road


**Fig. 13.3b** The consequence: the child was hit by a car


**Fig. 13.4a** Non-player character warns the user not to run a red light


**Fig. 13.4b** A NPC prompts the player to call emergency numbers

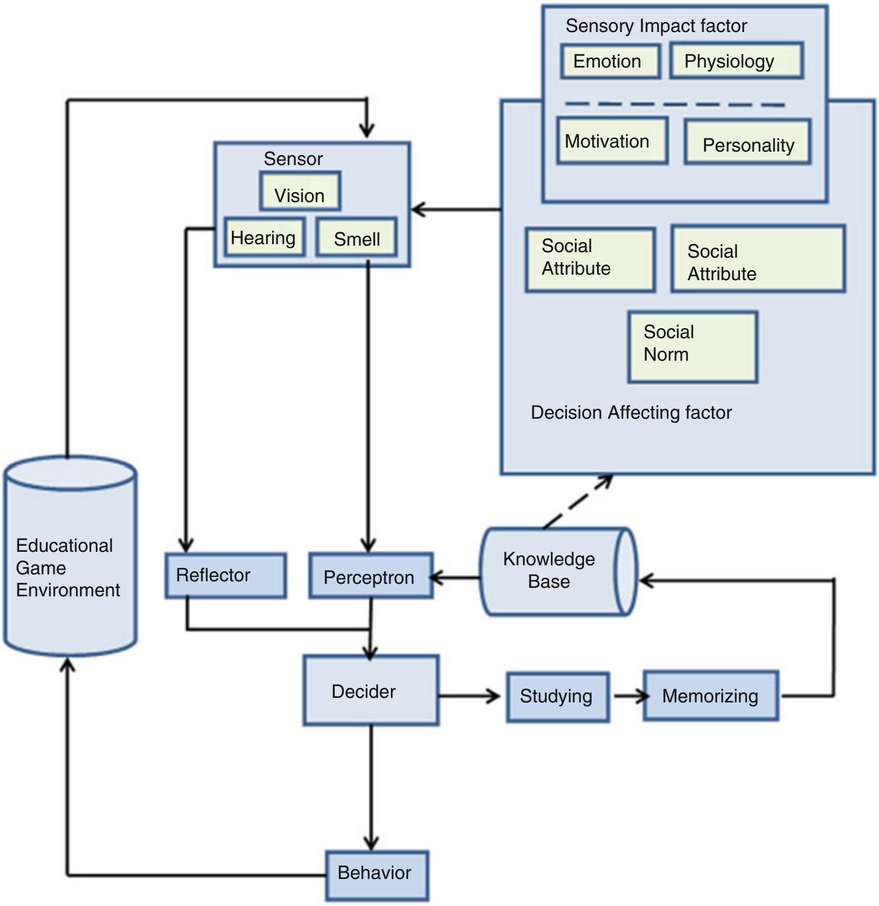


**Fig. 13.5** Cognitive structure of a NPC

general cognitive structure is shown in Fig. 13.5. An NPC will receive stimuli from the environment with sensors such as vision, hearing, and smell. The stimuli will then be transferred to the perceptron and be interpreted semantically by a knowledge base, which is called the perceptron. Based on the NPC's motivations, social norms, and personality, the NPC would select the most appropriate response from the action list in the knowledge database that is suitable for the current situation. This proposed cognitive model can simulate human cognition, reasoning, and decision-making processes.

We can create different cognitive models for different game scenarios and simulate perception functions in different scenarios to describe the NPC's perceptron. Decision affecting factors in Fig. 13.5 can affect perceptron. The factor of social attribute can be replaced by NPC's social identity. The list of social identities can be used to identify the NPC's social relationships and perform specific behavior in a specific scenario. For example, in the scenario of hospital fire escape, NPCs who have family relationship will try to escape together. In this scenario, the perceptron of the NPC will apperceive his family members before practicing his escape plan.

Social norms are value standards of an individual's social behavior. It can be used to measure and judge the social impact of individual's behavior. People's social behaviors need to be constrained by social norms as they have direct impact on social life and social order. Therefore, the use of social norms in serious games will help create NPC's complex behavior. Social attitudes can be regarded as one's acceptance of social norms. People who accepts social norms will generally constrain their behavior by social norms.

In this chapter, we mainly discuss two attitudes that impact on NPC's decision-making: obeying or rejecting social norms. For example, patient safety is nurses' first requirement in emergency. Social norms require them to help and guarantee patient to escape from the dangerous situation. Therefore, nurses who obey social norms will not escape by themselves but help patient to escape first. On the other hand, nurses who do not obey social norms will escape by themselves and leave the patient alone.

Additionally, psychological variables like motivation, personality, and emotions also have impacts on the NPC's decision-making. However, relevant researches in this area are insufficient so far. Psychologists point out that motivation is the internal driving force of human behavior. Using motivation module in serious games can indicate the internal driving force of NPC's behavior. Maslow's hierarchy of needs reflects the common law of human behavior and mental activities (Maslow 1954). He portrayed human needs in a five-level hierarchy: physiological, safety, love/belonging, esteem, and self-actualization.

Safety needs and love/belonging needs affect people's evacuation behavior in unexpected disasters. Based on the safety needs, people will choose to escape in the event of unexpected disaster. However, their choice will go beyond safety needs if they have love/belonging needs about family affection. For example, at the time of the earthquake, most people would escape to the exit as soon as possible. Under the influence of family affection, some parents won't escape until they find their children.

Personality forms the basis of our predictions concerning NPC's future behavior in given situations. Researchers generally agreed that the big five personality traits "OCEAN" is the widely examined theory that can describe personality. According to this theory, people's personality is divided into five types: openness, extraversion, conscientiousness, agreeableness, and neuroticism (Su et al. 2007). Each factor has positive and negative values. O+ refers to open mind, curiosity, creativity, and wide interests, whereas O- refers to closed mind, caution, and resistance to change. C+ refers to self-discipline, sense of duty, leadership quality, and persistence, whereas C- refers to irresponsibility, carelessness, and shrink. E+ is perceived as extroverted, talkative, and sociable, and E- is perceived as introverted, shy, and aloof. A+

means friendly, submissive, and cooperative, while A- is perceived as detached and antagonistic. N+ is perceived as sensitive and unstable, while N- refers to stability and calm.

While dealing with emergencies, people with O+ (open-minded) and C+ (responsible) can reasonably use a variety of countermeasures. They will be more patient, more curious, and more eager to explore new situation. They won't be flurried and overwhelmed for the sudden change, but can effectively respond to the change and make best decisions for the current situation, whereas people with E- (aloof), A- (unsocial), and N+ (sensitive) are more likely to have extreme behavior, such as jumping off the building, when dealing with unexpected disasters.

Emotion is another important attribute of an NPC. As it will affect one's behavior, a believable NPC behavior model should take it into consideration. Among many emotion models, OCC model, PAD model (Mehrabian 1996), and EMA model (Gratch and Marsella 2004) are the most popular. The PAD model uses dimensions to represent all emotions. The P (pleasure) scale measures how pleasant or unpleasant one feels about something; the A (arousal) scale measures how energized or soporific one feels; and the D (dominance-submissiveness) scale measures how controlling and dominant versus controlled or submissive one feels. In the PAD model, values for three dimensions are in the range of $-1$ to 1. There will be eight subspaces to define the type of emotion according to their emotional qualities.

In the EMA model based on emotional cognitive psychology, it regards emotion as the evaluation of events. In the EMA model, "desirability" and "likelihood" are the evaluative variables. They can get corresponding value according to the environmental evaluation assessed by the perceptron. "Desirability" is associated with the goal of the subject, while "likelihood" refers to the expectations for the event. Each evaluation variable has its value. The value of "desirability" includes "desirable" and "undesirable." When a certain event could help the subject to achieve their goals, it is desirable; otherwise, it is undesirable. Similarly, the value of "likelihood" could be *unlikely*, *likely*, or *certain*. Different values of evaluation variables and their combinations can result in different emotions, which provide a theoretical basis for constructing emotional inference rules.

In our serious games, an NPC's emotion can be triggered by a perceptible object in the scene or an activating event, also known as the source of those emotions. Over a period of recovery time, emotion would gradually return to the baseline level of state (calmness). Each source has an emotional impact on the NPC. Emotion would be generated by a perceptible object in the scene or an activating event and would affect the NPC's perception ability in reverse.

We use fuzzy productive rules to design the decider (Zhen et al. 2011). Based on cognitive appraisal theory of emotion, a set of productive rules for NPCs could be used for different game themes. The premise of the rule is the knowledge of the status of appraisal variables and decision impact factors. The conclusion of the rule results in various behaviors, including emotions.

## 13.5 Evaluation of the Child Safety Games

### *13.5.1 Waterside Safety Game*

We created a scene of a typical Chinese Jiangnan-style village and a waterside landscape as the game scenario. The virtual character can be controlled either by game AI or by the player as an avatar to increase the user engagement. When controlled by game AI, the virtual character has autonomous behavior and can react to other approaching virtual characters. There are two modes to control the character. In the *autonomous* mode, the character will automatically roam in the scene. Users can follow the character from different perspectives. The *user-controlled* mode allows the player to fully control the avatar. Autonomous mode can be used to demonstrate the safety educational game. Different objects in the scene would be given different preset semantic information to instruct the virtual character how to perceive them. For example, when the character perceives a fruit stand, he would obtain semantic information "something edible" (associated with physiological needs). The character would then make the appropriate behavior that is driven by the motivation. He may stop and look (see Fig. 13.6). When the character perceives a stray dog, they would obtain semantic information "something dangerous" (associated with safety requirements). The character would then run away (Fig. 13.7). When the character is around a boat and *sees/hears* someone fell into the water, he would get speedboat's semantic information "something for rescue" (associated with belonging needs). The character would drive the speedboat to save the drowning victim (Fig. 13.8).

In the user control mode, users could explore potential risks in the virtual scene by themselves.

**Fig. 13.6** The character stopping and looking at the fruit stand

**Fig. 13.7** Escaping panic when encountering a stray dog

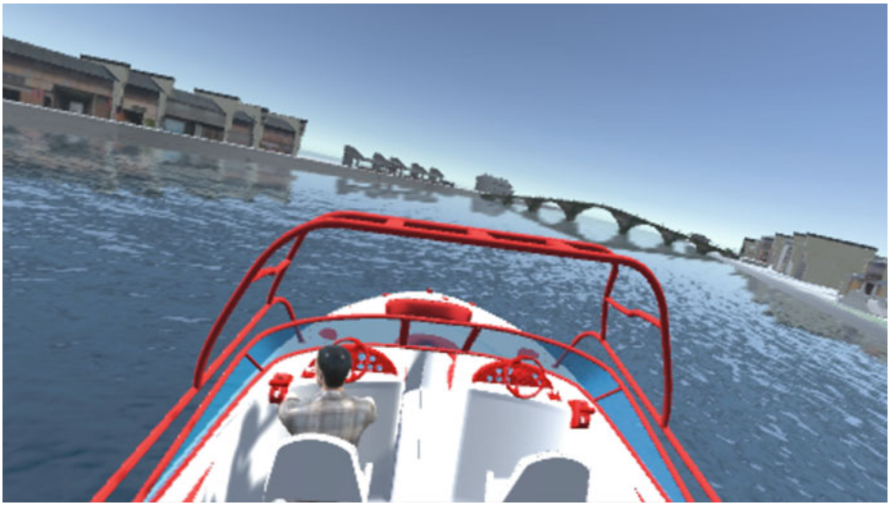

**Fig. 13.8** Driving a speedboat to save a drowning victim

In order to investigate how many security risks children can learn from the game, we conducted an experiment at Zhenan Road Primary School in Ningbo. Ninety-eight participants aged 12 played the game and completed the questionnaire.

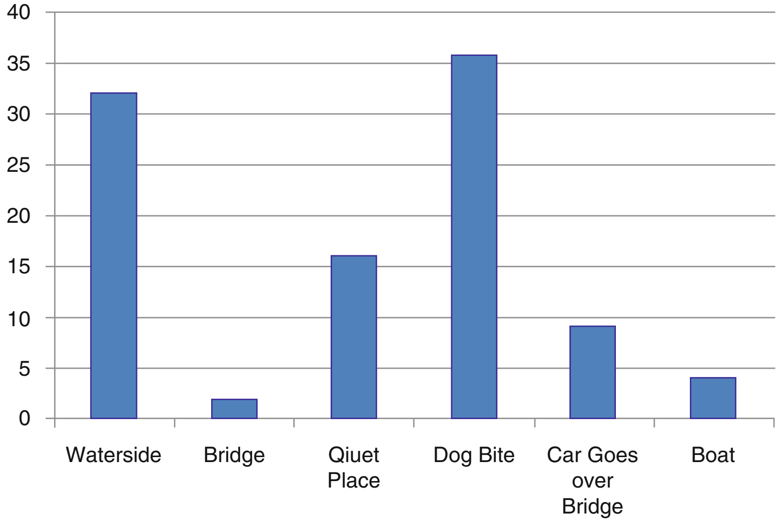


**Fig. 13.9** Hazards identified in the risk assessment survey

Having investigated several village safety problems in the game, we found that bitten by dogs was regarded as the most dangerous factor (36 participants agreed), followed by water safety (32 participants agreed), as shown in Fig. 13.9. Survey results showed that students are aware of all safety problems in the game as we expected. Therefore, it is meaningful to raise students' awareness of safety with our educational game.

We also investigated children's reaction to the danger. The results showed that when a child falls into the water, 85% of participants would use boat to save the victim and 15% would find a doctor. That indicated that the participants had high awareness of water safety.

### *13.5.2 Earthquake Escape Game*

China is an earthquake-prone country. Using serious game to aid earthquake escape education has a considerable realistic significance in China. We model a 3D hospital scene of the affiliated hospital of School of Medicine in the Ningbo University. In the game scene, users can observe events that may occur in an earthquake from the first-person perspective; NPCs are designed to help users to learn the knowledge of escape. A variety of collapse and fragmentation effects are achieved based on the physical model, and the flame effect is simulated with particle animation (Fig. 13.10). When the earthquake occurs, the avatar is in the hospital waiting room (Fig. 13.11); he may want to take the escalator to go downstairs. If so, an NPC nurse will come to remind the user to use the stairs instead (Fig. 13.12). When the player is


**Fig. 13.10** After the earthquake, fire caused by electrical short circuit


**Fig. 13.11** The character in a hospital waiting room before the earthquake


**Fig. 13.12** An NPC nurse advises the player not to take the escalator

blocked by fire, he will receive a text prompt to find the nearest fire extinguisher. Once he got the fire extinguisher, he will get instructions on how to operate the equipment and so on. To make the game more interesting, we present a health bar for the character. If the virtual character is injured or stayed too long in the smoke, his health will be reduced. When the health reaches zero, the character will fall and die. Using this mechanism, we added a sense of urgency and ask the player to flee the outpatient building as soon as possible. This also discourages the exploration behavior of some players who try to test the limits of the game and experience various options.

By analyzing students' game play in the earthquake scenario, we found that when the earthquake occurs, 6% of students would stand still, 62.2% of them would run to the escape stairs, and 31.8% of them would feel overwhelmed and walk around. When encountered with the fire, 92.8% will walk around it or find a fire extinguisher to put out it. But there are 7.2% of players who were not aware of the dangers and tried to pass through the fire without any protection.

We also discovered that boys were more likely to keep on going when they face a dangerous situation than girls. For example, instead of walking around, some boys will go into the fire and the black smoke directly. Therefore, we added the health bar for the virtual character in the game to discourage adventures. Once they stayed in the dangerous environments or touched hazardous objects, their life values would be reduced. If the virtual character jumped off the building or is injured by a falling

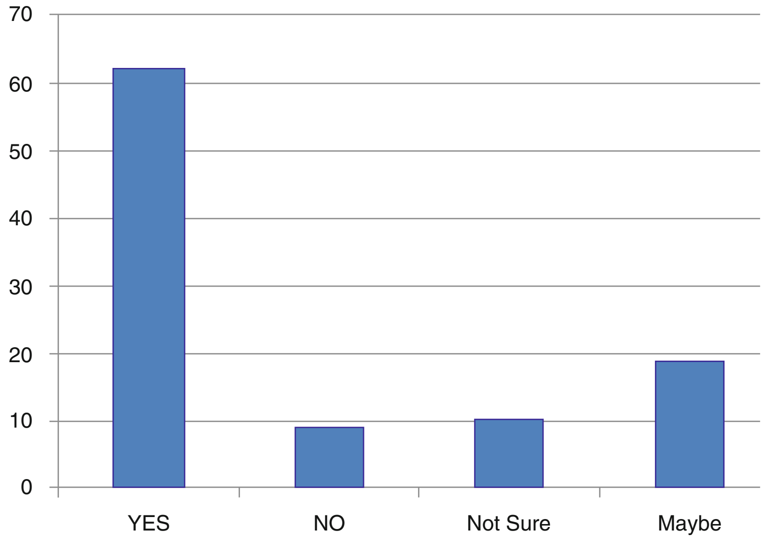


**Fig. 13.13** User learning effect statistics

object, he will lose some health values. More seriously, the character would die if his health becomes zero. This may visually show the importance of escape.

The purpose of this educational game is to enable students to learn basic knowledge of earthquake escape and be aware of the dangers that exist in the earthquake, as well as serious consequences that are caused by improper behaviors. After experiencing the escape with the earthquake escape game, we found that pupils had a better understanding of the dangers and learned the basic knowledge of escape and simple precautions that can help them survive.

We did a survey among students who have played above two games. When they were asked whether they are able to deal with the real danger similar with the ones they experienced in the games, 62% of students said yes, 9% of students said no, 10% said they had no idea, and 19% said they might (see Fig. 13.13). The result showed that after playing the safety educational games, pupils' escape knowledge and safety awareness have increased significantly.

In summary, safety education with serious games will have remarkable effect and are more engaging than traditional methods of safety education. This method can attract children's interest and raise their safety awareness. Players will learn escape knowledge unconsciously by playing the games. It is feasible to use games as an educational tool to raise awareness of child safety and to increase disaster and emergency preparedness.

**Fig. 13.14** Trials of the child safety games in a primary school

## 13.6 Conclusions

It is a meaningful work to use serious gaming technology in child safety education. This chapter summarizes some of our explorations in this field. We proposed the concept of danger zone on the basis of analyzing children's accidental injury cases in China. According to children's psychological characteristics, 3D serious games were developed to assist child safety education in primary and secondary schools. To increase the interactivity and interest, we proposed a cognitive model and used it to design game characters with believable behavior. A water safety educational game and an earthquake escape game were designed based on actual accident cases. The player could roam in the game scenes, experience the importance of safety by exploring (trial and error), and obtain visual impression of the danger. Trials have been carried out in 40 primary schools in Ningbo, China (Fig. 13.14). Students liked this new safety educational method very much. The proposed method is a reference for further development of child safety educational games.

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# Chapter 14
# Using Serious Games to (Re)Train Cognition in Adolescents

**Wouter J. Boendermaker, Margot Peeters, Pier J. M. Prins, and Reinout W. Wiers**

**Abstract** Cognitive training has been studied in the context of many psychological disorders, including attention deficit hyperactivity disorder (ADHD), anxiety, depression, and addiction. While several studies have found clinically relevant training effects, both in preclinical (experimental) and in clinical settings, cognitive training is often experienced as rather boring. Therefore, several studies have recently started to integrate serious gaming techniques into cognitive training paradigms to enhance motivation to train, especially among younger subjects. In this chapter, we discuss the relevant theoretical frameworks supporting both the trainings and the gamification techniques, review several attempts that have been made so far, and discuss the progress that has currently been made. The chapter will end with a number of recommendations, based on published evidence, as well as our own experience in this field.

**Keywords** Cognitive training • Substance use • Adolescents • Serious games

## 14.1 Introduction

Although any game that is used for a serious purpose, other than mere entertainment, can be viewed as a *serious game*, many are developed with the specific purpose of improving motivation on a serious task, such as a training or educational experience, by making it more enjoyable. For example, there has been a recent surge in the development of video games aimed at improving (mental) health (Kato 2010). Many of these *games for health*, as they are often called, are aimed at adolescents and

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young adults, as gaming is very popular among those age groups (Entertainment Software Association 2014). But adolescence is also a sensitive period when it comes to mental health, potentially making serious games especially effective at this age. The question central to this chapter is, how can the scientific evidence for cognitive training principles be used as a basis to effectively improve mental health in adolescents, using serious gaming techniques? In the following section, an overview will be presented detailing what is currently known about cognitive training, underlining the importance of using the right principles or paradigms. In the third section, we will take a closer look at the role of motivation in adolescents. The fourth section will describe the current state of affairs of cognitive training games aimed at adolescents, and the final section will finish off with some recommendations regarding the development and study of these games.

## 14.2 Training Cognitive Processes

Adolescence is a developmental period characterized by a considerable increase in the prevalence of internalizing problems, such as anxiety and depression (Paus et al. 2008), as well as externalizing behavior, such as experimenting with risky behavior (Steinberg 2007). The European School Survey Project on Alcohol and other Drugs (ESPAD; Hibell et al. 2012) showed that almost 60% of the 100.000 students in the survey reported to have consumed at least one glass of alcohol at the age of 13 or younger, 2% had already been drunk at that age, and 18% had tried illicit drugs at least once during their lifetime. Although this behavior does not necessarily lead to mental problems, excessive contact with psychoactive substances at this age can lead to misuse, school dropout (Singleton 2007), and ultimately addiction problems later in life. As such, early intervention is important to prevent escalation. While there are numerous prevention and treatment programs available, which tend to focus on explicit education, their efficacy is sometimes limited (Werch and Owen 2002), which may in part be due to the fact that adolescents have a hard time reflecting on and making changes to their behavior in general.

Interestingly, recent evidence has emerged that many of these adolescent mental problems are associated with specific cognitive deficiencies, such as a weaker working memory capacity (WMC; Martinussen et al. 2005) or a tendency to selectively attend to information or approach stimuli that strengthen the problematic behavior (Bar-Haim et al. 2007; Peckham et al. 2010; Wiers et al. 2013). For example, many anxious people have a tendency to attend to negative or threatening information (Bar-Haim et al. 2007), whereas heavy alcohol users selectively attend alcohol-related information (Field and Cox 2008). Similarly, an approach bias has been found for alcohol-related cues in heavy drinkers (Field et al. 2008; Wiers et al. 2009) and for cannabis cues in cannabis users (Cousijn et al. 2011; Field et al. 2006).

Training, or retraining, these cognitive processes can be effective in decreasing symptoms. We can distinguish between two closely related types of cognitive training (Wiers et al. 2013). First, there are training paradigms aimed at modifying the maladaptive cognitive biases (cognitive bias modification, CBM). These training procedures are usually disorder specific, as they often involve stimuli (i.e., pictures, words) related to the disorder. For example, attentional bias modification in long-time heavy substance users has been associated with a reduction in drinking (Fadardi and Cox 2009) and a significantly longer time to relapse (Schoenmakers et al. 2010). Similarly, Amir et al. (2009) and Schmidt et al. (2009) showed a decrease in anxiety symptoms in clinically anxious patient groups (for a recent review, see Kuckertz and Amir 2015). Another type of CBM, aimed at modifying automatically activated action tendencies to approach or avoid disorder-related stimuli, was effective in reducing alcohol intake directly after training (Wiers et al. 2010). When this type of retraining was added to regular therapy for alcoholism, relapse 1 year after treatment discharge was reduced with 13 % in patients who received this type of training, compared with those who received sham training or no training in addition to regular treatment (Wiers et al. 2011). This finding was recently replicated in a large study ($N > 500$), with evidence for statistical mediation (the clinical change was mediated by the change in automatic action tendencies) and moderation (patients with a strong approach bias profited more from this training than those without a strong approach bias, Eberl et al. 2013). In addition to training attentional bias and approach bias, positive memory biases have also been targeted with different methods, such as evaluative conditioning (pairing the focal category alcohol with negative stimuli, Houben et al. 2010) and selective inhibition (pairing the focal category alcohol with an inhibition signal (Houben et al. 2011a, 2012), with initial promising results in heavy drinkers.

Second, there are more domain-general cognitive control functions, such as WMC and impulse inhibition, collectively called executive functions (EFs). Deficits in EF are implicated in many psychological disorders, such as addiction, attention deficit hyperactivity disorder (ADHD), and autism spectrum disorders (ASDs), but also internalizing disorders such as anxiety and depression. These EF deficits are related to functional impairments and specific problem behaviors (Hosenbocus and Chahal 2012). The three components of the executive system that have received the most research attention are working memory, inhibition, and cognitive flexibility (Diamond 2013). Meta-analyses have shown that the working memory and inhibition of school-age children and adolescents with ADHD are mostly impaired (Martinussen et al. 2005; Wilcutt et al. 2005). Executive impairments have also been reported in school-age children with ASD on measures tapping planning, inhibition of prepotent responses, and self-monitoring (Robinson et al. 2009). Although these EF deficits have been consistently found in ADHD and ASD and are related to functional impairments and specific problem behaviors, they are not specific enough for use as clinical markers for these disorders (Geurts et al. 2004; Hosenbocus and Chahal 2012). In addiction these cognitive control functions are needed to regulate the impulsive reactions involved in the substance-related biases. There is some evidence that when inhibition (Houben and Wiers 2009; Peeters et al. 2012) and WMC (Grenard et al. 2008; Thush et al. 2008) are weak, they can fail in their regulatory function, leading to an imbalanced cognitive system (Wiers et al.

2007). However, support for a causal relationship, where impaired control functions are a result of adolescent substance use, is weak (Wiers et al. 2015).

Impairments in EF have also been linked to problems with self-regulation and the development of disruptive behavior problems such as found in oppositional defiant disorder (ODD) and conduct disorder (CD; Schoemaker et al. 2013). Results regarding working memory performance in children and adolescents with ODD and CD, however, are less consistent than those found in youth with ADHD. Although cognitive deficits are widely recognized to be an important component of anxiety (Moran 2016), fewer studies have assessed the relation between EF deficits and internalizing problems such as anxiety and depression. Anxiety, both self-reported as well as experimentally induced, is thought to restrict WMC by competing with task-relevant processes. According to cognitive theories, anxiety problems are related to impairments in attention processes.

Just as cognitive biases can be influenced through targeted training, cognitive control functions can also be strengthened through training, with the best results in children with relatively weak WMC (Holmes et al. 2009), such as children with ADHD (Klingberg 2010). While cognitive training effects do not always generalize to other cognitive abilities (Shipstead et al. 2012), increasing WMC can also lead to reduced drinking in problem drinkers with strong automatic positive associations with alcohol (Houben et al. 2011b). Training working memory in adolescents in order to improve their executive attentional control also resulted in positive changes in symptoms of trait and test anxiety, increased inhibitory control, and reduced attention to threat (Hadwin and Richards 2016).

Interestingly, these two types of cognitive processes are intimately intertwined in several disorders. For example, when cognitive control is low, the impulsive processes tend to better predict the maladaptive behavior (Wiers et al. 2013). Although there is ample evidence in favor of cognitive training (for more elaborate reviews, see Klingberg 2010, Wiers et al. 2013), it is not without controversy. Some authors (e.g., Cristea et al. 2015, Emmelkamp 2012) note that the quality of the evidence in support of CBM is limited, with reported changes pertaining mainly to the targeted biases, but limited or no effects on mental health outcomes. Similarly, the notion of strengthening cognitive functions through training has also been subject of recent debate (e.g., Shipstead et al. 2012). While this chapter is not a place to repeat this debate on the efficacy of cognitive training, it may help to distinguish between the nature of the training studies that show or refute cognitive training effects with regard to the experimental settings. Importantly, while effects have generally been limited in single-session studies with unmotivated participants (usually heavy-drinking students who do not wish to reduce their drinking (e.g., Schoenmakers et al. 2007) or community smokers who do not wish to quit (Kerst and Waters 2014)), studies in which cognitive training has been delivered to clinical samples as add-on to regular treatment (Eberl et al. 2013; Schoenmakers et al. 2010; Wiers et al. 2011) have yielded significant improvements in clinical outcomes.

To conclude, although cognitive training can be a promising basis for the development of serious games, the specifics of the disorder, the target population, and the training paradigm are very important for the efficacy of the training.

Another important aspect that can influence the efficacy of cognitive training is the participant's motivation, which is where serious game techniques may play a pivotal role (Gladwin et al. 2011).

## 14.3 Motivations

Similar to physical training exercises, most cognitive training paradigms rely on a substantial number of repeated actions over multiple sessions to reach a training effect. To sustain performance during these training sessions, it is necessary to reach and maintain a state of motivation high enough to continue training. But prior to the actual training, adolescents first need to be motivated to consider participating in a training. That is, they need to have a basic *motivation to change* their problematic behavior (Boffo et al. 2015). Although the negative effects of adolescents' problematic behavior are often obvious to those around them, adolescents themselves sometimes lack the realization that they even have a problem. For example, many adolescents don't think of their heavy alcohol use as problematic or harmful (Johnston et al. 2012). This is not strange when we look at the developmental function that many risk behaviors, such as alcohol use, can fulfill. Adolescents often engage in risky behaviors to attain or increase peer status or to receive positive evaluation of peers (Crone and Dahl 2012; Sommerville 2013; Steinberg 2007). Peers and their perspectives become increasingly important in adolescence, and adolescents' behavioral decisions are often taken while conforming to peer norms and peer cultures (Baumeister 1990; Forbes and Dahl 2010), making it harder to provoke behavioral change. For that reason, it is important that intervention strategies are developed in line with the perceptions of adolescents, and they can only be effective when aspects such as motivation and attention are taken into account. In contrast, most CBM studies feature adult patient samples, where most participants have a long history of substance use problems and are thus more motivated to change their behavior. As such, there are important motivational differences between adolescents and adults that have to be taken into account when designing a motivating intervention, such as a serious game training. When this *motivation to change* is low, it may be best to combine cognitive training with other types of intervention (Wiers et al. 2013), such as motivational interviewing (Miller and Rollnick 2002) or (cognitive) behavioral therapy. But even when participants are somewhat motivated to make a behavioral change, they often find cognitive training paradigms to be long and boring and have a hard time believing that a simple computer task can help them to, e.g., control their substance use (Beard et al. 2012). As such, they may still need to be motivated to complete the full training. Applying serious gaming techniques to evidence-based training paradigms may help adolescents to increase their *motivation to train*. Specifically, serious games as an intervention strategy for adolescents have the ability to anticipate on two important cognitive developments that characterize adolescence: (1) development of behavioral control and (2) increased sensitivity for reward. Adolescents are (hyper)sensitive for reward, but at the same time have difficulties in controlling their behavior as behavioral control continues to develop into late adolescence (18–20 years; Blakemore and Choudhurry 2006; Luna et al. 2004). Not yet fully developed behavioral control skills increase the chance that insufficient attention is giving to the task, specifically when the task is long and boring, subsequently resulting in incomplete or inefficient training. Adolescents with externalizing behavioral problems such as ADHD and CD are particularly at risk because of their deficits with behavioral and motivational control functions (Dovis et al. 2013; Krueger et al. 1996). Exactly this group of youngsters is at the greatest risk for developing addictive behaviors (Peeters et al. 2015) and therefore could benefit most from an efficient intervention strategy. As such, serious games can significantly advance the field of interventions for adolescents in general and particularly for adolescents with externalizing behavioral problems. Compared to traditional intervention approaches, serious games can be better equipped to grasp attention and increase adolescents' motivation to complete the training (Dovis et al. 2013). Moreover, the competitive and arousing character of games can better connect to the perceptions of adolescents (Granic et al. 2014), status increase and competition are two often observed reasons of why adolescents engage in risk-taking behavior (de Boer et al. 2016; Sommerville 2013), and these factors could act as important reinforcers when efficiently processed in a serious game. The gameplay and the competitive character of serious games may increase the rewarding and motivating capacity of the intervention; however, notion should be taken in how rewarding elements are incorporated (Dovis et al. 2013; Boendermaker et al. 2015b).

## 14.4 Serious Games and Cognitive Training

As we have seen in Sect. 14.2 of this chapter, it is important to consider the delicate nature of evidence-based cognitive training paradigms in order to be able to use them as a basis for serious games. Most paradigms are structured as repeated stimulus-response exercises and tend to be very sensitive to slight structural changes (e.g., changing the display duration of a cue from 500 to 2000 milliseconds may give very different results; Field et al. 2013). As such, there is always a risk involved in adding game elements to such paradigms, as these may render the task less effective. Boendermaker et al. (2015b) propose a model that features several techniques for turning cognitive training tasks into serious games.

The model distinguishes between several steps on a dimension going from purely serious (i.e., the original, evidence-based paradigm) to purely game (e.g., the use of a commercial game for serious purposes; see Fig. 14.1). Many studies already report including some sort of reward system (Step 1), such as a prize, money, or course credits, for participation (Anguera et al. 2012; Jaeggi et al. 2011) or specifically based on task performance (e.g., points for speed and accuracy; van Deursen et al. 2013). Although this is probably the easiest step to include, it has been suggested that using such extrinsic rewards can also hinder performance (Jaeggi et al. 2014) by undermining intrinsic motivation (Deci et al. 1999).

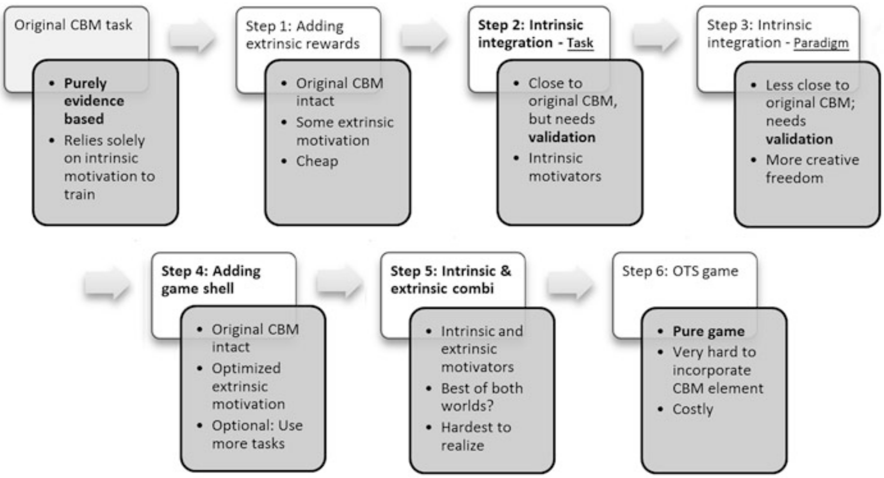


**Fig. 14.1** Gamification model. Six gamification steps from evidence-based paradigm (CBM) to commercial "off-the-shelf" (OTS) games (Adapted from Boendermaker et al. (2015b). Copyright 2016 by Elsevier Ltd. Reprinted with permission)

The next two steps involve making more elaborate changes to the original training task, increasing the motivation to train through the use of intrinsic motivators, such as game elements, making it more fun to perform the task itself. As such, the motivating elements are fully integrated into the training paradigm. For example, the Cheese Ninja Game on Facebook (Boendermaker et al. 2015a) is based on the go/no-go paradigm used by Schoenmakers et al. (2010), aimed at retraining alcohol-related memory bias. In this game, the user controls a mouse character running through a tunnel, grabbing pieces of cheese and avoiding cats. These playful cues are selectively paired with pictures of alcohol- and nonalcohol-containing beverages in the background in order to retrain the alcohol bias. First, results among heavy-drinking students indicated that adding (social) game elements increased their motivation to train, compared to a regular go/no-go training. Gamito et al. (2014) used a set of similarly gamified mobile trainings of attention, working memory, and logical reasoning to train cognition in clinical alcoholic patients. Although they found an overall increase of cognitive abilities for both the game and nongame training groups, the game training group showed a more pronounced improvement in frontal lobe functions from baseline to follow-up, suggesting that the addition of mobile game elements to existing training paradigms may result in even better training effects. Dennis and O'Toole (2014) developed a mobile game based on the dot-probe paradigm (originally developed by MacLeod et al. 1986) to retrain attentional bias in highly trait-anxious young adults. In their game, participants were presented with cartoon characters showing angry or neutral/mildly positive facial expressions, their reaction to which was rewarded with jewels based on speed and accuracy. A single session of this training managed to reduce subjective anxiety and observed stress reactivity. In contrast, the Shots Game (Boendermaker et al. 2016), which incorporates the same dot-probe paradigm, aimed at retraining alcohol attentional bias, produced less positive results. This game, which features an animated slot machine with an elaborate reward system, did not reduce alcohol attentional bias, whereas the nongame dot-probe training did. Moreover, motivation to train decreased over time in both the game and the nongame conditions, suggesting that the added game elements were not enough to counteract the tiresome nature of the training.

Taken together, these games all introduce a richer context for the points earned, while remaining as close as possible to the original, evidence-based training task. Nevertheless, it appears that not all game elements are beneficial to the training efficacy, and despite the changes being minimal, there is still a relatively high risk involved of losing some of the key elements of the paradigm in the process of creating the game, potentially making the training less effective. Therefore, these games should always be revalidated by comparing them to the original training task.

An alternative can be to add game elements *around* the original training task, like a shell, while leaving the task itself relatively unchanged (Step 4 in the model). Although this approach minimizes the chance of rendering the training less effective, it also leaves the relatively boring task intact, motivating the user primarily by rewarding good task performance, *after* that performance. As such, a possible drawback to this approach is that the motivating part remains separated from the training task. Such motivators are sometimes called extrinsic and are viewed as inferior to intrinsic motivators (Deci et al. 1999). An advantage of this game type is that it allows for the incorporation of several different training tasks in one serious game. For example, in the CityBuilder game (Boendermaker et al. 2013), players can train different cognitive aspects, such as working memory and inhibition, as well as more CBM-related processes such as attention and approach bias. The original training task is presented on top of the game, as shown in the right pane of Fig. 14.2.

By performing well on the training (i.e., based on speed and accuracy), they receive points that can be spent buying a variety of objects to build a custom city, after the training block is over. Going one step further, combining these two

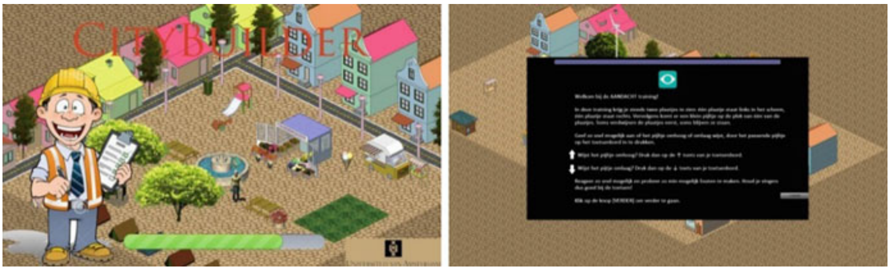


**Fig. 14.2** Shell game "CityBuilder." Game screen on the left, embedded training task overlaying the game screen on the right (Adapted from Boendermaker et al. 2013. Copyright 2016 by the authors. Reprinted with permission)

approaches may result in the most optimal balance between training efficacy and motivational elements. For example, Braingame Brian (Prins et al. 2013) is a game training aimed at improving different cognitive control processes, such as working memory and inhibition. It has managed to extensively integrate several original training tasks into a game shell while remaining very close to the original paradigms. Verbeken et al. (2013) and van der Oord et al. (2012) have used Braingame Brian and reported positive training effects in obese children and children with ADHD, respectively. Another example of this game type is Watermons (Dörrenbächer et al. 2014). The Watermons game adapts a task-switching training, based on the alternating-runs paradigm from Karbach and Kray (2009), into an elaborate game world filled with engaging story lines to motivate participants. First, results showed increased training effects compared to a regular nongame version of the training in terms of reaction times and switch costs, as well as a higher motivation to train (Dörrenbächer et al. 2014). The final step toward gamification concerns the use of a commercial, off-the-shelf (OTS) game to measure improvements on cognition, such as visual short-term memory and selective attention (Boot et al. 2008). Although this strategy could arguably have the highest motivational value, most commercial games were not developed with nonentertainment purposes in mind and as such are often filled with visual and auditory distractors. Moreover, many cognitive training paradigms, especially CBM related, include disorder-specific stimuli, which may be hard to incorporate into an existing commercial game. As such, although there have been reports of cognitive benefits of commercial gaming (for a review, see Granic et al. 2014), they seem less well suited for targeted cognitive training games.

## 14.5 Recommendations for Future Research and Development

Serious games can be a promising new way to reach at-risk youth, through prevention as well as intervention, and cognitive training can be a firm scientific basis for the design of those serious games. As this field is relatively young, more research is needed to determine for whom these cognitive training programs work best and which game elements should be used or avoided. For example, the different game types described have thus far not been compared directly to see which one works best. Similarly, certain game elements, such as loud sound effects, flashing visual distractors, and real-time scoring, can also distract the participant during their performance and lead to reduced task performance (e.g., Katz et al. 2014). This underscores the importance of validation of the new gamified measure, with regard to the degree to which the game elements add to the cognitive load during task performance. Other interesting questions concern, e.g., whether the combination of explicit and implicit motivational techniques, targeting motivation to change, e.g., through motivational interviewing or cognitive behavioral therapy, as well as motivation to train through the use of game elements that work best. Perhaps a serious game can be designed that incorporates elements of implicit cognitive training as well as more explicit cognitive behavioral therapeutic elements. And if game elements can improve cognitive training efficacy, can they also improve the quality of cognitive assessment data (Hawkins et al. 2013)?

While many of these questions are currently being studied (e.g., Lumsden et al. 2016), several critical notions also apply. For example, as a typical cognitive (re)training program can take up to 600–2000 trials over multiple sessions (e.g., van Deursen et al. 2013), serious games that incorporate such large numbers of trials will need to keep participants' motivation high over a longer period of time in order for them to be able to sustain a sufficient level of performance. Interestingly, the use of game elements may therefore also introduce a new risk: when the training is presented as a game, participants' expectations of the level of fun during training will be raised, as the word "game" undoubtedly creates certain expectations based on previous experience (Boendermaker et al. 2015b). As such, they now expect to be entertained. If this does not happen, however, their disappointment may also be greater than when they did not have these expectations in the first place (as is presumably the case when participating in a regular, nongame training intervention). Because of this, it is important to use the word "game" with caution when presenting a serious game to participants. It would also be interesting to study participant expectations about the (gamified) training and their effects on motivation and treatment outcome. A related problem that may affect research outcomes is that after participating in a game training, the sudden lack of motivating elements in the post-training assessment measures could demotivate participants to do well, potentially canceling out any training effects.

Despite the evidence that game elements can increase participants' motivation for doing cognitive training, the level of fun may never reach that of commercial games. However, the question is, can or should we expect them to be? Buday et al. (2012) suggest that a direct comparison with commercial games should perhaps be avoided altogether. Given that even expensive commercial games sometimes fail to keep critical players interested for long, there is indeed a challenge for typically low-budget serious games to keep motivation reasonably high while keeping expectations relatively low. As such, serious game research, as well as training outcomes, could benefit from keeping expectations modest.

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# Chapter 15
# Promoting Healthy Adolescent Lifestyles Through Serious Games: Enacting a Multidisciplinary Approach

**Ian Dunwell, Laura A. Condon, Kim C. M. Bul, Alexandra R. Lang, Sarah Atkinson, Neil S. Coulson, and Emily Collins**

**Abstract** Long-term health risks associated with unhealthy lifestyles present a significant current and future burden for healthcare providers. Adolescence represents a critical time for intervention, as habits formed during this period can persist throughout adult life. Given the prevalence of gaming as an entertainment medium amongst adolescents, and subsequent potential for engagement, the use of serious games to promote changes in lifestyle behaviour offers a potential solution. Creating such games requires a breadth of multidisciplinary expertise, working collaboratively to create research-informed designs which reflect both behavioural theory and entertainment game design best practices. In this chapter, challenges and benefits associated with multidisciplinary design are identified and discussed, with strategies presented to overcome and avoid potential issues. With reference to a current project, the perspectives of the theorist, iterative designer, and game developer are contrasted, providing a reference for future projects implementing multidisciplinary approaches to serious game design.

**Keywords** Games for health • Multidisciplinary design • Lifestyle intervention • Serious games

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## 15.1 Introduction

Making healthy lifestyle choices which influence factors such as diet, activity levels, sedentariness, and habit formation has the potential to dramatically impact an individual's mental and physical well-being. For an adolescent audience, mediums such as gaming have extensive and existing uptake as a recreational activity; hence, the notion of using games for "serious" purposes such as supporting a healthy lifestyle is one of clear interest. Whilst a substantial number of significant examples of work in this field already exist, still little evidence or advice is available in the early stages of game design which can answer concretely which specific game mechanics, aesthetics, or narratives may be most effective for a given audience and context. Configuring and enacting an effective multidisciplinary approach to design, therefore, is frequently essential.

In its initial discussion of behavioural theories and concepts, this chapter notes the challenge in aligning intervention design and behavioural theory to effective game design. Such alignment is noted as particularly important when considering deploying games for use beyond a training or classroom context, where intrinsic motivation to play adds the need to provide an engaging and compelling gameplay experience. Design methodologies for serious games often posit the need for a broad range of expertise to be engaged throughout the life cycle, typically including roles for the subject matter expert, educator, theorist, researcher, game designer, and end user. Enacting such models in practice, however, can be problematic: "design by committee" is a term seldom used with positive connotation, and gaps in understanding and objectives need to be carefully managed and addressed. In describing multidisciplinary approaches to serious game design, this chapter outlines some common areas of misunderstanding or missed opportunity, seeking to reconcile these various roles under a unified vision.

The final section of this chapter describes current work in progress within the European-funded PEGASO (Personalised Guidance Services for Optimising Lifestyle in Teenagers) project. PEGASO seeks to explore the synergistic use of a wide range of technology-based interventions, including wearable sensors, data-driven goal setting and monitoring, and smartphone apps. Discussion is provided of how input has been combined to create a mobile serious game, intended to be played by children beyond a classroom context, and engage them with a wider platform of lifestyle improvement and (self-)management tools. In doing so, we note the ability of games to partially decouple content and aesthetic from behavioural objectives, in this case creating a "zombie survival" experience which includes nutritional learning alongside its motivational components and mechanics. In concluding, we reflect upon the lessons learned in creating the serious game, describing how current and future work can be best implemented and benefit from a multidisciplinary approach.

## 15.2 Background

Given both the human and healthcare costs associated with the increasing prevalence of obesity and its various comorbidities, throughout the developed world, a wide range of interventions exist that aim to encourage individuals to develop or maintain healthier habits (Ward et al. 2015). One of the most commonly cited restrictions to the effectiveness of these interventions is a lack of motivation on the part of the participant, alongside a lack of time and difficulties in accessing sufficient proportions of the target group (Baert et al. 2011; McGuire et al. 2014; Toobert et al. 2002). These issues, along with a rise in the accessibility of technology, have encouraged the implementation of interventions employing digital games, which could potentially incorporate all the benefits of more conventional eHealth interventions, such as cost-effectiveness (Elbert et al. 2014), alongside added advantages of greater engagement through enjoyment and inbuilt fostering of intrinsic motivation (Prensky 2003).

Educational approaches which seek to influence behaviour have, historically, focussed upon conveying knowledge of facts, rather than rewarding and supporting positive behaviour change. Given the complexity of monitoring and managing issues such as self-efficacy (Bandura 1977), it is understandable that approaches have tackled awareness; however, their success leads to new interventions needing to explore mediums and methods that go beyond conveying this awareness. It can often be observed that knowledge is already common amongst a target population, be it the ability to connect activity to long-term health benefits or broadly identify healthy food choices. It is failure to apply this knowledge in practice that often generates a problem or concern, rather than the absence of the knowledge itself. A focus on knowledge transfer is often tempting, as it is relatively easy to design for, and typically more straightforward to measure through assessment or survey than real-world behaviours. Yet the need remains for interventions which carefully identify existing knowledge amongst the target demographic and focus on its application rather than acquisition.

Prior research into game-based interventions in relation to healthy lifestyle adoption has demonstrated games to be successful in comparison to other non-game, eHealth interventions (Krebs et al. 2010; Portnoy et al. 2008). Moreover, DeSmet et al. argue that coupled with the increased intrinsic motivation inherent in serious games compared to other computer-based methods, as well as the greater levels of interactivity and visual interest, games may be a better medium of delivery (DeSmet et al. 2014). This is in line with other assertions that as long as the games present adequate challenges, participants are willing to spend more time on them than they would engage with traditional learning methods (Bourgonjon et al. 2010). Several reviews have found large effects on knowledge acquisition (Connolly et al. 2012; DeSmet et al. 2014), and it has been argued that knowledge is the easiest outcome to influence (Portnoy et al. 2011). However, it should also be noted that knowledge is also typically a more straightforward construct to operationalise and measure and, partly as a consequence of this fact, has often already been addressed. Behavioural interventions commonly seek to impact populations who "know" the correct choice or action, be this the basics of a healthy die, or smoking abstinence, but fail to carry it out in practice.

Serious games can prove effective tools for behavioural change, as demonstrated by a growing number of large-scale evaluations around such diverse topics as healthy eating (Baranowski et al. 2011b), exercise (Monaghan et al. 2015), physical rehabilitation (Alankus et al. 2011), road safety (Dunwell et al. 2014), and chemotherapy adherence (Kato et al. 2008). However, achieving successful impact requires a range of factors to be considered, including how best to accommodate the ability level of every player, identify and improve their knowledge and skills, and relate outcomes to their needs and values. Games are not silver bullets for solving engagement or motivational issues with interventions; rather, employing a game to solve these issues requires careful consideration of how the game will be sufficiently compelling and "fun" to stimulate intrinsic motivation and engagement during play.

Nonetheless, engagement and the capacity to stimulate intrinsic motivation are often posited to be particular advantages of serious games (Lima et al. 2015). This is often a reflection of the time spent engaging with entertainment games and the focus and attention they demand and stimulate as a "flow" experience (Csikszentmihályi 1990; Komulainen et al. 2008). A primary challenge in creating a serious game, therefore, is how best to balance educational and entertainment aspects, such that these characteristics of engaging gaming are retained whilst still imparting serious outcomes (Zyda 2005). This issue lies at the core of effective serious game development, particularly in contexts where the game itself is expected to generate motivation to play, rather than being reliant on integration into a classroom setting. The examples that exist of serious games reaching large numbers of users suggest that a predominant focus should be on creating a "fun" game, and a user experience that incorporates immersion and flow, with educational aspects realised through wider communities, linked content, or without being explicit to the player (Meyer and Sørensen 2009); immersion allows the player to be engrossed in the gameplay and develop a sense that the proposed experiences are personally relevant, and flow creates a sense of concentration through a balance between the challenges presented and the skills of the player, keeping them engaged and interested (Csikszentmihályi 1990). A game which inspires the user to learn, rather than goes to great lengths to overtly teach them, could be argued as more likely to be more successful in the absence of extrinsic motivation.

Gaming presents an opportunity to engage adolescents through a medium which is increasingly prevalent as a leisure activity (ISFE 2012). Furthermore, time spent gaming is presenting an issue for conventional messaging mediums. Television advertising, for example, is reducing in reach (Nielsen 2015), creating a pressing challenge not just to improve interventions but retain the impact of existing ones. One of the main arguments for the use of serious games over more traditional methods or interventions is how ubiquitous and familiar technology is for adolescents, making game-based delivery comfortable and potentially enjoyable (Wong et al. 2007). Learning through play has been argued to encourage faster, more implicit learning (Prensky 2003), and digital games in particular have been argued to be especially motivating, encouraging a greater level of engagement than other activities (Gee 2003). Games are also enjoyed by a large number of adolescents, and this expectation of enjoyment can be capitalised upon in educational contexts; whilst children may not be interested in participating in traditional learning interventions, digital games are still seen as a fun activity, and they therefore engage with them expecting to enjoy it (Sim et al. 2006). As a consequence, in the correct contexts, games can prove an ideal medium for the delivery of educational material and have demonstrable ability to impact behaviour (Baranowski et al. 2011a; Connolly et al. 2012; DeSmet et al. 2014) though harnessing this potential to achieve specific target behaviours is a challenging task.

There is some disagreement as to whether the duration of a game-based intervention impacts its effectiveness (DeSmet et al. 2014; Primack et al. 2012). However, DeSmet et al. (2014) argue that Primack et al.'s (2012) finding that shorter interventions are more effective was confounded by the inclusion of studies that involved a one-session intervention and immediate measurement of outcomes. Therefore, as most interventions are over a longer period of time and most meaningful outcome evaluations are not taken immediately thereafter, it could misleadingly appear that the full intervention's duration does not relate to effectiveness. Several reviews have agreed that game-based interventions appear to be effective irrespective of age or gender (Brox et al. 2011; Primack et al. 2012). However, Brox et al. (2011) highlight that there are likely to be variations in preferences across different demographics and that these need to be considered and taken into account for the intervention to be successful.

Similarly, DeSmet et al. (2014) also concluded that the duration of the gameplay itself appears to be unrelated to effectiveness. Previous investigations have utilised relatively low durations, averaging to only 4 h overall, and though it has been argued that the lack of effectiveness of a game-based intervention could have been due to a short playing time (Rahmani and Boren 2012), this does not appear to be supported by the findings of reviews. Conversely, games that were played on only one occasion demonstrated changes on behaviour that only just approach significance. The effect sizes of each, however, vary considerably, suggesting that it may not be as simple as certain durations being more effective. Instead, it is likely that other game characteristics impact it more considerably such as use of a narrative, in-game challenge, or scaffolding levels (Malamed 2012; Lu et al. 2012). This highlights the need to consider temporal increments of follow-up measures when assessing effectiveness relating to game duration, an element that can be considered and planned for at the design stage.

In summary, despite the positive evidence for the impact of games throughout this section, challenges persist: How can the tension between the "fun" required for engagement best be reconciled with the goals of an intervention? What do prior evaluations, which often look at heavily operationalised measures of behaviour to determine success, tell us about how to best design future serious games? Whether a game "can" work is a question not dissimilar to whether a book, television campaign, poster, or any other medium or messenger can change a behaviour; the fundamental question is one of relative efficacy and design, questions which existing large-scale studies rarely address in detail. In the next section, the multidisciplinary approach to serious game design in healthcare is discussed in terms of how it might best be structured and enacted to help resolve these challenges.

## 15.3 Games for Health: A Multidisciplinary Project

A common theme amongst the existing works outlined in the previous section is their goal of utilising games to engage the user and subsequently adjust their behaviours towards those which facilitate positive long-term health and well-being. Thus, the design challenge is typically how best to engage and retain users whilst ensuring serious objectives are met. A multidisciplinary approach, combining expertise in game design with that of psychologists in understanding behaviour and behavioural change, human factors engineering, educational theorists, public health experts, technologists, and clinicians, is commonly adopted in such projects to give added benefit of broad and complimentary knowledge bases (Abeele et al. 2012). A range of frameworks for serious game design exist (Marne et al. 2012; Rooney 2012), which are valuable aids to structuring the design process, yet implementing them effectively requires strong multidisciplinary coordination and effort.

Whilst these knowledge bases are complimentary, effective communication which appreciates and defines the roles of the individual disciplines within the project team is essential. Tensions can not only arise from gaps in knowledge but also from a lack of shared primary goals: the researcher may look for success in terms of trial outcomes, the game developer in terms of commercial exploitation, and the clinician in terms of the ethical, practical, plausible, and usable solution. These goals are often codependent; without research evidence of effectiveness, commercial exploitation is likely to be hindered, though can also partly conflict and contradict. A typical example of this occurs in translating entertainment game design best practice, which can often imply features such as open communication between players to capitalise on social benefits, to ethical constraints. A healthcare intervention is unlikely to be capable of allowing open communication between its participants using a platform in the absence of moderation and monitoring, particularly in the case of an adolescent or younger audience. Such moderation is not easily scalable and can affect the ability to create a viable and sustainable exploitation model post-project.

Another example of tension can occur when engaging end users in an iterative design process, wherein prototypes are trialled and examined for efficacy and reception at multiple stages. It should be noted, here, that entertainment game design best practices typically advocate putting a game in front of end users as frequently as possible, though often without the methodological rigour that typically accompanies healthcare intervention. In effect, end-user trialling of entertainment games often trades off robustness of findings for flexibility and frequency, seeking to rapidly identify and answer design choices and aesthetic decisions as and when is required. Adapting and implementing such models so as to balance research rigour with the pragmatic and rapid nature of such trialling is often a key challenge for researchers involved with serious game projects. Handling this well requires a good degree of separation between trials of effectiveness, which require rigour and methodological clarity to create compelling evidence, and design-level iteration seeking to ascertain potential efficacy; research here still needs to be intrinsically valid but may need to be less ambitious in its attempts to create generalizable findings to function effectively as a design aid.

From such examples, the need for communication of constraints which may be beyond those in typical entertainment game, or healthcare intervention, project at an early stage is clear. Similarly, understanding of shared research, commercial and project objectives, and their interdependencies during a project start-up phase is key. The goal of the project team should be to transfer learning and understanding of their expertise across the team, rather than function as isolated experts. Human factors engineering, for example, can complement the strategies and goals of other disciplines, particularly in supporting the experiential elements of gameplay and subsequent design and development iterations of game mechanics. The onion model is a key human factors tool (Wilson et al. 2008) and typifies the interactions between technology and the user within the context of their environment. This model is universally applicable to technology development providing essential considerations in the development of games and gaming technology. For example, taking into account the user interaction with the game, the game use in context and other influencers of gameplay provides a systems perspective of game use from which experiential learning about user requirements and gaming behaviour can be achieved.

Incorporating a wide breadth of expertise when following this approach to serious game design has clear benefits; however, it also requires careful management of collaborative effort to ensure clear direction (Eck 2010). In particular, the major role the technologists and game developers play in creating the final product can result in them having a similarly large influence in low-level design decisions, which may run contrary to the original design vision or conceptual model. These conceptual models themselves also often require design-level application by theorists to enable an effective practical end result to be communicated to developers. Taking the onion model as an example, whilst it provides a robust and tested conceptual framework at a high level, it can lack meaning for developers and risks interpretation as positing ideals rather than practical solutions.

Similarly, behavioural theories are a valid starting point for intervention design, but managing this relationship between multidisciplinary contributions to the design of serious games can be particularly challenging given potentially divergent views on how a game design should be realised to address specific behaviours. For example, one perspective is that of the simulator, where the game itself simulates a behavioural task, with the user asked to replicate the task in the hope or expectation that this behaviour will transfer to the real world. This is grounded in substantive evidence that the effect of simulation works in a training context (Hays et al. 1992), and the greater the fidelity of a simulation, the greater the degree of learning or real-world behavioural transfer that might be anticipated. Interestingly, however, taking the example of aircrew training, for which this method is arguably one of the most direct and well-known applications of simulation training for real-world behavioural transfer, introducing game-based elements has been shown to improve performance when compared to a non-gamified control version (Mautone et al. 2008). This effect contradicts the paradigm that the more realistic a simulation, the greater the impact, as a game-based element is intrinsically less "real" than a pure simulation. Given this, a particular problem for simulation-based approaches arises for games seeking to engage the user in contexts where the simulated behaviour lacks intrinsic appeal as a form of entertainment. So, whilst a flight or driving simulator has popular and commercial appeal, similar attempts to provide, for example, simulated experiences of infection control on hospital wards have been met with limited uptake amongst nursing staff (Dunwell and Jarvis 2013).

The risks associated with setting up an interdisciplinary team to create a serious game as a healthcare intervention are outlined in Table 15.1. Ultimately, a project team needs to share and reconcile their understanding of intervention design and game design principles and practices. An advocation here is that all members should engage with the state of the art, both in terms of gaming and existing healthcare intervention. Hands-on experience with current games and interventions can be invaluable in aiding shared understanding, yet sometimes surprisingly difficult to promote, since unlike the majority of entertainment media, individuals tend to identify readily as either "gamers" or "non-gamers". However, developing this shared experience can be critical in reducing the risk of poor communication of design ideas and concepts due to limited cross-disciplinary understanding. In the following section, differing perspectives on the design process for healthcare serious games are considered.

## 15.4 Design Processes and Perspectives

The previous section discussed and highlighted the need to create an effective project setup for multidisciplinary game design. In this section, the design process itself is considered in more depth. Considered here are a range of different perspectives on which a design can be formed: behavioural theory; an iterative, user-centric, research perspective; or as an adapted entertainment game design process. This is particularly relevant in designing games for promoting healthy behaviour and healthy lifestyles, since a typical game is likely required to simultaneously engage the user whilst showing research evidence of effectiveness. Such evidence is likely essential if games are to be subsequently taken up by healthcare providers and, even in the case of games available to the general public via platforms such as Google Play, is required to ethically describe the benefits of the game. This section ends with the risks and reconciliation strategies for these various approaches. The goals, expertise, and governance unique to an individual project preclude a ubiquitous design approach; however, as these approaches are likely to relate to the multiple

**Table 15.1** Project setup risks and strategies for an interdisciplinary healthcare game

| Project design and setup | | |
|---|---|---|
| Risk | Impact | Mitigation strategies |
| Lack of shared understanding of games as a medium | Difficulty for game designers in communicating concepts effectively. Over- or underestimation of the levels of engagement and motivation a game may yield | Challenge individual's perception as "non-gamers". Consider early stage interactive gameplay workshops to play and discuss relevant entertainment games |
| Lack of shared understanding of healthcare interventions | Difficulty for intervention designers in communicating best practices and principles. Lack of identification of existing barriers, making it difficult to employ a game to address them | Engage with existing interventions. Consider again interactive workshops to experience and discuss relevant interventions |
| Lack of shared understanding of constraints | Risk of having to redact or remove features post-ethical review, compromising design, or introduce additional overheads (e.g. chat moderators), limiting scalability | Review ethical framework early and document clearly requirements of adherence. Consider common issues – participant communication, social media use, competition between participants |
| Lack of clarity on research objectives and researcher role during development | Frequency of iteration with participants may be hindered as a result of requiring unnecessary breadth or generalisation. Clashes can arise between pragmatic approaches in game development and academic rigour | Consider where viable a flexible and "as needed" approach to engaging end users when questions are raised, rather than fixed schedules. Define clearly who will lead in identifying research questions for iterative testing and how these can be made flexible to accommodate agile development |
| Lack of clarity on overall project objectives | Failure to prioritise different objectives. Disjoints in project team, often between industrial and academic goals | Seek to identify links between evaluation of impact, commercial exploitation, and project goals. Define clearly IP ownership and "best-case" scenario at project conclusion |

disciplines involved, considering their similarities and differences can be of clear value in promoting a shared understanding through design and development.

### *15.4.1 The Theory-Based Design Perspective*

From the theory-based perspective, the most important aspect of game design for healthy lifestyle interventions, at least in terms of behavioural determinants, rather than clinical outcomes, is the incorporation of appropriate theories on which the game itself and the wider intervention can be based. Behaviours do not occur in isolation; any human behaviour results from interactions with many other behaviours and is influenced by multiple factors that contribute to bringing about action performance. A number of reports suggest that blending theories relating to enjoyment and those relating to educational elements of game-based interventions is vital in creating effective serious games (Baranowski et al. 2011a; DeShazo et al. 2010; Kato 2012; Papastergiou 2009). Therefore, unsurprisingly, those that have combined game-based theories such as transportation theory (Green and Brock 2002) with those relating to behavioural prediction such as social cognitive theory (Bandura 1977) have reported greater improvements in outcomes than those focusing solely on the latter. Whilst whether this is due to more significant direct impact or greater ease in identifying, and hence operationalising, likely outcomes may be debated, though in either case a theoretical grounding brings advantages to design and subsequent evaluation, making it possible to argue a combination of game-based and behavioural theory should be incorporated into future games in the area.

Evidence suggests that games can be used to scaffold learning, a process involving the provision of temporary support to assist individuals in learning, which is gradually reduced as the student improves. Instructional support, for example, via worked examples, is especially effective, particularly in relation to knowledge acquisition (Yaman et al. 2008). This may be because of how scaffolding can help players refine their strategies and thus enhance their learning (Fisch 2005) whilst also avoiding the frustration associated with repeated failures. This is currently implemented in games through the incorporation of supportive tools (such as more information or hints and tips) at known bottlenecks within the games (Davis and Miyake 2004) and therefore can be easily added to educational games. One proposition is that adding multiple kinds of scaffolding to games may enhance their effectiveness (Ma et al. 2007).

Key to many theories of behaviour change is individual or group readiness to change a behaviour. The stages of change theory or transtheoretical model, hereafter TTM (Prochaska and Norcross 2001), addresses this cycle by capturing different stages of people’s readiness to change. Application of this theory to serious games has a number of advantages over other theories. Firstly, it addresses behaviour change as a cyclical process that leads to lasting behaviour change over time rather than as a linear process (e.g. quitting smoking). For example, people can be prompted and guided to various stages of readiness to quit in order to maintain a nonsmoking lifestyle over time. Secondly, the TTM addresses recovery from relapse as part of behaviour change maintenance. A relapse of a behaviour occurs when a person regresses to old or problematic behaviours, such as smoking, and can happen at any stage in the process, but it occurs most notably and with the highest cost to the overall process of behaviour change when people are in a final maintenance phase.

In addition, both intrinsic and extrinsic motivation to perform a behaviour initiates the behaviour change pathway. Self-determination theory (hereafter SDT) posits that that behaviour is the product of inherent and intrinsic psychological needs that foster health and well-being, namely, competence (to seek to control and outcome and experience mastery), relatedness (to interact with, be connected to, and experience caring for others), and autonomy (to be the causal agent of one's own life). SDT posits that behaviours are likely to be initiated, and changes are most likely to be sustained if the source of motivation to act is intrinsic (Ryan et al. 2006).

A recent and comprehensive framework of behaviour change, the Behaviour Change Wheel framework (Michie et al. 2011), hereafter BCW, operates with the underlying assumption that effective behaviour change interventions must be constructed using a systematic approach that is firmly grounded in the research evidence base for specific target behaviour(s) (e.g. eating more fruit and vegetables) in a context that is relevant to a specific target population (e.g. adolescents).

At the core of the BCW framework is the COM-B model of human behaviour (B) incorporating the psychological components associated with behaviour change: capability (C), opportunity (O), and motivation (M). Components of the COM-B model are interdependent and work in unison to help change a target behaviour or support the long-term maintenance of a target behaviour once an individual has adopted it into their regular behavioural pattern (i.e. habit formation). Of key importance is generating player motivation to engage with behaviour change interventions, including games, to exploit opportunities for socialisation and increasing self-efficacy and not just purely regarding the game as a medium for knowledge transfer. Incorporated within the BCW and COM-B model, the principles of human motivation are represented in PRIME Theory (West 2007). This shows a hierarchical structure with higher levels of motivation generated in response to stimulation by both the internal and external environment and acting as stimuli for lower levels of motivation that are well established within the individual, such as reflex responses and intrinsic needs. Having self-awareness, however, introduces reflective processes in relation to our actions and our internal mental representations of self and exerts a degree of self-control over our behaviour to reinforce this mental representation or identity. Therefore, where acting upon impulse may allow a stimulus with the strongest motivational force in relation to our wants and needs to control behaviour, conversely, reflective evaluation of our intention to act in relation to future desires may lead a deferral in our priorities at that moment in favour of future action planning. In this way, behaviour techniques which incorporate user-led approaches such as goal-directed behaviour, and target goal setting, can be exploited to sustain engagement and encourage behaviour change.

In summary, the strength of a theory-driven approach is the ability to identify at an early stage a validated framework for behavioural change. As discussed in this section, they provide detailed guidance and insight into the factors which may govern, or preclude, a change in behaviour. However, a corresponding weakness is the need to translate this theory to practice, in the form of a game. Considering the inherent complexity of a digital game, both as a technical undertaking and design exercise, it can prove challenging to translate a high-level concept, such as self-efficacy, to a low-level mechanic or feature within a practical design. Whilst possible to achieve, the risk remains that the implementation may diverge from or fail to fully represent the theoretical model, a particular risk if models are handed to developers or designers with limited knowledge of the theory themselves.

Regardless, taking any theory to a practical intervention requires the intervention then be subsequently evaluated, firstly to test whether the process defined by the theory is occurring and secondly to examine its efficacy in the specific intervention context. The next, research-driven, perspective examines how research during the design and implementation process is often enacted to iterate towards effectiveness.

### *15.4.2 The Research-Driven Design Perspective*

Clarity is required in the definition of this perspective, as the majority of serious game projects could be argued to be "research driven". Referred to here is the notion of end-user research within the development life cycle, which seeks to provide recommendations for subsequent design and development. Methodologies for enacting this commonly advocate iterative, and to a lesser extent, participatory design. A major challenge, therefore, is how best to define and enact iterative cycles, given the costs associated with game development – iteration may yield the solution to the majority of problems; the challenge is iterating within fixed timescales and resources. As a field, these are problems centrally addressed by human factors engineering.

The role of human factors engineering in the design and development of serious games is typically to advocate early user requirements capture, iterative participatory design, and user experience (UX) testing, so that problems are identified, understood, and mitigated in the design process, whilst positive user interactions and design features can be implemented for maximum user benefit. This is achieved through the utilisation of methods which explores how well a game and gaming features fit or does not fit into a user's lifestyle. It also considers the "interaction and mental models" of prospective users, whereby previous experiences and existing mental models contribute to a user's initial experience of gameplay. The interaction models will have a significant impact on uptake and use of the game, whereby mental models are either successful or not at engaging the user in the short term and then in the longer term (Portnoy et al. 2008).

In addition, establishing an understanding of what is being tested, when, and for whom helps to establish patterns of play, abilities, and preferences for gameplay that are relevant and essential for incorporation into serious game design aimed at a specific target population. Young people, for example, are "experts in the way they interact with the world and capturing this expertise is key to designing meaningful artifacts" (Iversen and Brodersen 2007). This concept pervades the development of technology more generally and is an important part of the development of serious games whereby young people will have prior expectations and needs which need to be met. These may correspond to consumer trends which should also be understood as they may not be articulated as well in this target group as by an adult population.

To this end, human factors assessment incorporates mixed methodologies in order to gain insight into aspects of gameplay. The combination of quantitative and qualitative data provides technology developers with complimentary data sets allowing for reflection on development to date and with a view to future improvements for user requirements. Utilising a mixed methods approach also enables the ability of participants with different competencies and skill levels to impart their views and needs of the technology platform. Not only does the approach look towards UCD in the development of the technical products, mobile apps, serious game, and wearable sensors, but the UCD ethos pervades the design and development of methods for eliciting user requirements.

The concept of tailoring to the player is one that has been supported by a number of reviews. For instance, DeSmet et al. (2014) conclude from theirs that although tailoring games to behavioural change needs (e.g. current lifestyle choices, current knowledge, level of motivation) does improve outcomes to some degree, this in itself is insufficient. Indeed, findings support the notion that tailoring is most effective when it is done on both theoretical concepts and the characteristics of the user rather than each individually (Noar et al. 2007). Furthermore, dynamic tailoring may improve these outcomes to an even greater degree, with continuous adjustments being made throughout the intervention (Krebs et al. 2010). When specifically applied to games, dynamic tailoring can be used to promote flow (by adjusting the level of challenge to the players' increasing skill), which as previously outlined may be highly influential in creating behaviour change (Wilson et al. 2008)

The level of prior gaming experience could also be an important aspect to account for; as for inexperienced players, learning the playing requirements may take so much concentration that it jeopardises engagement with the educational content (Schrader and Bastiaens 2012). Therefore, incorporating appreciation of the individuals' previous gaming experience and making appropriate adjustments may prevent this from occurring. However, very few serious games on this topic have utilised dynamic tailoring, making the concrete outcomes still somewhat unclear. In addition to the technical development of game design, important contributions from human-centred design, human-computer interaction, and user experience culminate in a holistic human factors approach. Particular focus upon core questions such as whether the user's underlying needs are met, whether the game fits within the user's lifestyle and social context, and whether it facilitates social connectedness all serve to provide insight into likelihood of uptake, adherence, and long-term engagement.

Semi-quantitative and qualitative approaches, such as qualitative interviews and open-ended questionnaires, form the basis of iterative development processes for game design. Focus groups also provide an appropriate form of qualitative data collection for user requirements capture and review for serious games. Furthermore, as a data collection strategy, there is evidence of their success when applied in cross-cultural research (Culley et al. 2007) so that research participants from different countries and backgrounds can produce data on a specific issue. Quantitative assessment tools such as the System Usability Scale (SUS) questionnaire (Brooke 1996) can also provide constant comparison of the game usability and provide developers with directed commentary and areas for further refinement/development. This quantitative tool is well validated in the field of human-computer interaction and so provides reliable data capture, to not only compare scores between different development stages but also to provide comparison between different experimental groups where cultural influencers may have an impact on game expectations and preferences.

With regard to serious game development, this approach also provides opportunity for the users to explore their preferences and priorities associated with game aesthetics including, but not limited to, the graphical fidelity and freedom of navigation, game mechanics, storyline, iconography, and modes of play. Such needs will also be fluid and varied dependent upon the target user population. The needs of adolescent users, for example, are varied (Kroemer 2005) and constantly evolving as they develop during their teenage years. As such a multi-method approach to data collection activities ensures that individual inter- and intra-variability is catered for and that the methods are inclusive of the various needs of the adolescent participants. Multi-method data collection is advocated (Lang et al. 2016) to meet those changing needs and capabilities, “to find methodologies which play to young people’s strengths rather than their weaknesses”.

As can be observed from this section, there are detailed and defined methodologies that may be applied to assess a serious game’s effectiveness during its development life cycle. Based on feedback detailed in the case study later in this chapter, participants can often feedback only from a single perspective, usually that of an entertainment gamer, and hence their recommended and desired features can prove ambitious, in terms of development time; divergent, given the aesthetic and creative dimension of gaming; or tangential or irrelevant, in terms of serious objectives. Nonetheless, this feedback can be highly valuable if appropriately understood and moderated in terms of the entertainment objectives of a game. The next section explores further the model of placing entertainment foremost and its implications on the design process.

### *15.4.3 The Entertainment Design Perspective*

From an entertainment design perspective, user engagement and retention are typical goals. Rather than seeking to provide an intervention which requires a specific context to provide extrinsic motivation, such as a classroom, a goal from this perspective is to stimulate intrinsic motivation by providing a game which is fundamentally fun to play. A range of tools are at a game designer’s disposal to engage and entertain the player, including storytelling and game mechanics that facilitate “flow” (Csikszentmihályi 1990) through challenge and feedback. A concept central to flow theory is the balance in task difficulty with a user’s perception of their ability: a game can achieve this through feedback on failure (the “near miss”) as well as success. In the literature relating to game enjoyment, immersion has been argued to be one of the aspects of intrinsic motivation to play the game (Ryan et al. 2006). As motivation is an important predictor of intervention success, this is particularly relevant to serious games. The aforementioned theories hailing immersion as one of the reasons games are successful in behaviour change contexts (Annetta 2010; Lu et al. 2012; Malamed 2012), and the assertion that immersion creates a greater sense of personal relevance for the player, all further support the importance of this outcome.

How, then, to achieve immersion? Focussing firstly on the narrative aspect, stories in serious games can seek to induce behaviour change (Lu et al. 2012), as the story can address issues relating to the behaviour being targeted and can promote the lessons underlying health-related behaviours. Existing research suggests that in terms of kinds of stories and the sort of setting they take place in, those involving an element of fantasy and role playing could be very well suited to serious games. Baranowski et al. (2011a, b) argue that role playing encourages individuals to have a greater personal interest in the outcome of the video game and allows easier delivery of reinforcement and experiential learning, such as interactions with characters that can describe or dictate experiences. Moreover, even when only looking at text-based learning materials, fantasy themes are reported to be more fun and result in greater engagement with both the characters and the educational message (Matheson and Spranger 2001). Evidence also suggests that fantasy themes do not just improve engagement but can also encourage significantly greater learning and knowledge transfer than contexts that do not involve fantasy (Parker and Lepper 1992). Educational games tend to incorporate "exogenous fantasies", in which the setting is used to make the educational setting more interesting, rather than alter the format or portrayal of the information. "Endogenous fantasies", however, incorporate the content into the game itself, making the two less readily discernible. It is this endogenous context that has been argued to be the most effective for learning, as it is something that occurs as a natural consequence of playing the game, rather than something players would have to specifically focus on (Prensky 2003).

Whilst narrative can be valuable, it is not essential that it serve as a central component of an immersive game. Classic games such as "Pac-Man" or "Space Invaders", or more recent games such as "Angry Birds", often use narrative to quickly frame a task, rather than tell a lengthy story. In the case of such games, attention is gained and retained through a repeated cognitive task, such as solving a maze, avoiding a shot, or firing a catapult. Essential here is consideration of feedback and flow. Evidence suggests feedback should not be too fast or exhaustive; this can reduce frustration through preventing players spending too much time on incorrect strategies but also restricts the extent to which players are able to learn through trial and error (Sun et al. 2011). Sun et al. (2011) report that when offered an error-check tool, participants relied heavily on this and thus did not internalise the knowledge or develop problem-solving strategies. Therefore, finding a balance between providing support and removing the need for engaging with the game content is needed, in relation to feedback as well as demonstrations and other forms of scaffolding. Noteworthy is the focus of Sun et al. (2011) on serious aspects of feedback, which often lie outside of the core task, in a summary or "Game Over" screen, rather than the rapid feedback intrinsic to any cognitive task within a game. This rapid feedback can operate at different levels, ranging from observing a character move when tapping a screen to scaffolding perceptions of success and failure through scoring or other mechanisms. A common tension in serious game design is ensuring these fundamental, low-level, frequent feedback mechanisms required for effective gameplay mechanics are not obstructed by additional feedback implied by educational or behavioural goals.

The kinds of genres that are most well suited to serious games should also be considered. The majority of existing serious games tend to be simulations, closely followed by puzzle games (Connolly et al. 2012), presumably due to the ease with which these kinds of games can be designed to deliver educational messages and information. However, Prensky (2003) posits that the genre should be dictated by the nature of the learning content and what kinds of in-game activities are likely to encourage this. It can be argued that educational games tend to prevent immersion by failing to connect elements of gameplay with those of content and context (Taylor et al. 2011). They also tend to be more restrictive than noneducational games in terms of moving around the virtual space. Consequently, these issues should be avoided through interconnecting the educational aspects of the game and the enjoyable, game-based aspects. Achieving this requires careful collaboration between theorist, game designer, and researcher. The next section reflects on the perspectives presented here to identify risks and strategies for serious game design which seek to take advantage of each of these viewpoints.

### *15.4.4 Reconciling Perspectives*

Given these multiple perspectives, effective codesign can be a demanding task. This may particularly be the case where project teams are distributed geographically or sectorally. Table 15.2 identifies a range of risks faced by serious game designs, and their resulting implications, suggesting a range of strategies to address them. Fundamentally, as with any multidisciplinary project, effective communication is essential. In particular, when seeking to reflect a high-level theory in low-level game mechanics and features, particular care must be given to ensuring theory is translated effectively to design, rather than "handed off" to developers in an abstract form. Decisions also typically need to be made through a combination of research-driven iteration and knowledge of best practices, appreciating the limitations users may have in providing feedback in multiple dimensions simultaneously. Often, iterated user studies seek to ascertain both engagement (whether a game is "fun") and efficacy or effectiveness (is it impacting, or likely to impact, behaviour?), though practical constraints often limit the ability to do so conclusively.

If sufficient heed is not paid to realising an underlying theory of behavioural change, as described under the theoretical design perspective, then the precise model by which a serious game can be expected to achieve impact can be difficult to retrospectively derive. This in turn has consequences for measuring its impact, in terms of identifying and operationalising constructs to be assessed within a trial. Similarly, without adequate end-user research, issues can be detected too late for a game to be adapted, and in lieu of compelling evidence of impact, the potential to exploit project outcomes and create a sustainable, long-term proposition is limited.

**Table 15.2** Risks and mitigation strategies for multidisciplinary serious game design

| Serious game design process | | |
|---|---|---|
| Risk | Impact | Mitigation strategies |
| Game fails to realise an underlying theory of behavioural change | Serious impact against behaviour is difficult to anticipate | Communicate theory clearly from the start. Engage theorists to aid in translating theory to practice. Avoid "handing off" theories at an abstract or conceptual level to nonexperts |
| Game fails to show impact on behaviour | Exploiting or promoting the project outcomes is challenging. Can be difficult to identify areas for improvement | Prototype and iterate flexibly and with agility. Ensure developer feed-in to understand practical constraints of iteration – iterating versions not suitable for feedback waste resources |
| Game fails to engage the user | This can severely limit the context in which the game can be deployed (requiring extrinsic motivation). Risks defeating the original purpose of a game in fostering intrinsic motivation | Ensure a good early understanding of what "works" in entertainment games. Accept and take advantage of the fact that entertainment aspects may be designed as abstract or tangential to serious goals, with a focus on engagement |
| Lack of clarity on technical specification and target platform(s) | Can impact costs of exploitation or trials. Feedback may be limited if skewed with performance issues due to hardware below specification | Define and understand target platform from the outset. Reflect on "typical" games using this hardware and impact of platform on usage patterns and habits (e.g. mobile games are often played in short bursts as a distraction). |
| Ethical or safety concerns impact the viability of distributing the end product | Can result in features being removed or redeveloped, limiting exploitation | Consider ethics and safety as integral to design. Reflect particularly carefully on social or multiplayer aspects: Do they require peer communication to be fun, and can this be achieved safely? |

Early iterations can also benefit from an emphasis on the entertainment perspective: feedback from users is likely to be richer and more detailed if they effectively engage with a prototype, and a clear "fun" factor from the outset is more likely to facilitate such engagement.

Some final considerations relate to the practical and ethical aspects of serious game design for healthcare. Identifying a target platform early on may be an obvious task, though consideration of the technical limitations it imposes should be simultaneous to developing an understanding of users' expectations and usage patterns on the platform. These can link to behavioural models: a smartphone can be available outside of the confines of home or office, though play sessions are more typically in short bursts, averaging around 5 min (Newsworks 2015).

The implications of platform can hence impact choice of behavioural model, as well as entertainment design. Finally, as a healthcare intervention, ethical considerations cannot be overlooked. These can frequently impose further design constraints: allowing players to communicate openly is common in entertainment gaming, yet allowing adolescent participants to communicate within a healthcare intervention requires detailed management and moderation. Hence, care needs to be taken in developing designs which either accommodate communication and competition ethically and safely or avoid implementing game mechanics that fail to work effectively in their absence. The next section illustrates how these various factors have been accommodated in multidisciplinary design within the large-scale PEGASO project.

## 15.5 A Case Study: The PEGASO Project

In this section, work on the PEGASO (Personalised Guidance Services for Optimising Lifestyle in Teenagers) project is presented. In particular, a reflection on the multidisciplinary project setup and design process is provided, noting how they were tackled with reference to the previous two sections. Within PEGASO, the role of the game is seen primarily as engaging adolescents with linked tools and technologies which, if used, have a direct impact on their health and well-being. Adopting such an approach has an immediate benefit in freeing the game to focus upon engagement and entertainment, yet as a serious game, it remains essential to consider its impact beyond uptake. Hence, all three perspectives presented in the previous section are relevant to the project: it must be informed by behavioural theory, so as to influence lifestyle change, whilst encapsulating educational and entertainment aspects as a serious game.

As a whole, the project structure consists of 17 EU partners, reflecting its goal to deliver not a serious game in isolation but an integrated suite of mobile tools and services. An essential first step in implementing the serious gaming aspect of the project was to identify theoretical, research, and development contributors and establish clearly the objectives of the game. A degree of scope existed here to provide an end product which could have ranged from an augmented reality "exergame" to a nutritional learning quiz. In the process of establishing aims and objectives, review of ethical and safety frameworks illustrated the difficulty in providing location-based or physical activity games to the target audience pragmatically. With the game also required to fulfil a role as a motivator, an argument also existed to ensure the game be as accessible as possible, something augmented reality, location-based gaming, or exergaming could limit. Initial scoping, therefore, developed a design brief for a mobile game which engaged the user in other PEGASO components whilst conveying nutritional knowledge linked to lifestyle (Turconi et al. 2003).

Other approaches in healthcare have sought to use entertainment games purely as motivators, for example, for insulin adherence in diabetic adolescents; approaches have been devised which "lock" a mobile gaming platform and release it on confirmation that treatment has been administered (Slater 2005). Yet from the theory perspective, the adopted COM-B framework (Michie et al. 2011) posits a broader consideration of behaviour than motivators alone. Combing this input with the entertainment perspective, the first design concept in PEGASO related to the behavioural models in the previous section is that of an "energy" bar. Here a direct analogue is made to "freemium" games, which are free to play but encourage microtransactions by the player. In an entertainment context, these transactions can be loosely grouped in terms of immediate rewards (cosmetic items such as character clothing or new levels), time-savers (allowing the user to avoid a real-world wait of hours by purchasing an upgrade or in-game item), or benefit multipliers (faster experience point gain or other progression bonuses). In an entertainment context, the behaviour these tools seek to motivate is purchasing. In the serious context of PEGASO, rather than requiring financial transactions, we instead focus on a "behavioural transaction" model, whereby the player is rewarded with energy for completing various tasks set by the other PEGASO system components, such as the health companion smartphone app.

Transactions range from simple, quick interactions, such as filling out a nutritional diary app for the day, or larger goals such as the aforementioned 10,000 steps, with correspondingly larger rewards. Such an approach is also beneficial on a technical level when seeking to develop and implement a large ecosystem of services, as it allows information transfer between services to focus on a single "energy" variable. This can then be utilised by game designers towards the goal of incentivising energy consumption and making it a commodity and service developers as a reward system for their particular behavioural objectives.

Taking as a game design goal, the use of energy and promotion of its value and desirability, an entertainment focus, is placed on the PEGASO game whilst retaining some serious informational elements within the broader theoretical framework. The game casts the player as a survivor of a "zombie apocalypse", helped by the fictional "PEGASO Institute" who provides them with a mobile device capable of a range of features, including extracting nutrients from food to upgrade abilities and deploying these abilities during the night to defend against zombies. The player can level up, being confronted with increasingly diverse ranges of foes, whilst gaining skill points to unlock new skills. They can also explore the world to find new abilities, which they deploy as "fast", "strong", and "defence" attacks through touchscreen gestures during the night, when waves of zombies attack. Energy is employed in a range of processes, including as an experience point gain multiplier, and is consumed when upgrading abilities. If the player reaches zero energy, they can continue to play, but cannot level up, promoting reacquisition of energy through the use of PEGASO services. Figure 15.1 illustrates a range of features within the prototype game.

The game also contains nutritional learning, based on knowledge identified as impacting behaviour (Turconi et al. 2003). As with any such study, caution should be afforded between correlation and causation; however, the nutritional knowledge is closely integrated into the game's mechanics, seeking to augment rather than obstruct them. One challenge in nutritional knowledge is going beyond the trivial

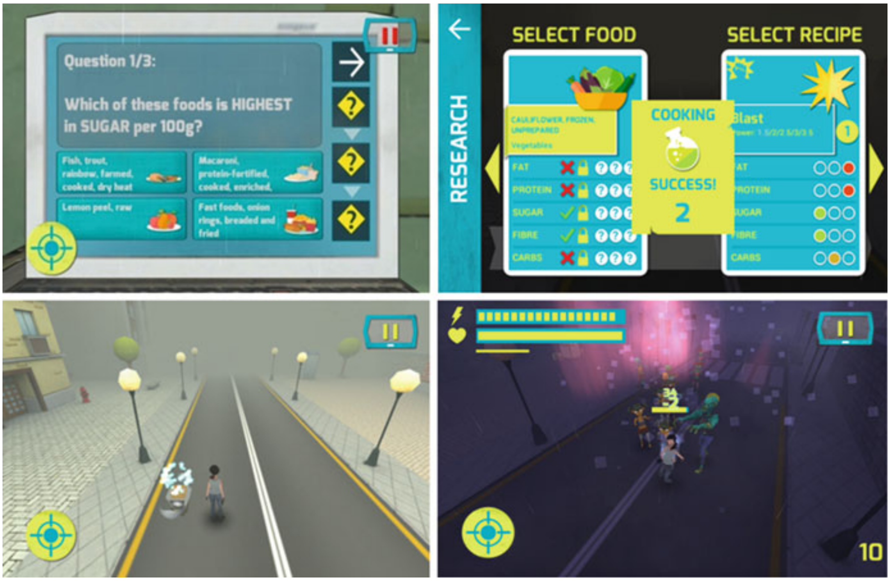


**Fig. 15.1** Screenshots of the PEGASO game. Clockwise from *top left*: (1) the nutritional "quiz", presented as the user "hacking" a laptop to gain an ability; (2) the research process, combining food based on nutrients to upgrade an ability; (3) the 3D game world explored during the day to find food; and (4) combat with zombies at night using upgraded abilities

question, e.g. "Which is healthier: an apple or chocolate?" to the more subtle. Two mini-games within PEGASO focus on the application and acquisition of nutritional knowledge: the first encourages the player to match "food cards" to recipes to upgrade abilities. The second has the player unlocking these abilities themselves by finding laptops scattered through the game's environment and "hacking" them by answering a series of questions on which foods are highest and lowest in nutrients. Given the goal of making these games consistently challenging rather than repetitive, a need existed for a high volume of food data to create a diverse range of questions. To achieve this, the US Department of Agriculture's nutritional database[1] was queried and its content used to create 3000 different food cards within the game. As such, the player can realistically expect each food card to have new properties and each hacking question to be unique in any given play through.

From the research perspective, the project implemented iterative and user-centric design, in common with a range of other interventions in the area (DeSmet et al. 2014). As DeSmet et al. note in this meta-review, participatory design is not shown to have impact on overall effectiveness. Experience within the prototyping and iteration process, which included a limited participatory element detailed more below, gives some insight into the causes. Firstly, fixed project timeframes, whilst

[1] https://ndb.nal.usda.gov/

required to enable partners to plan for end-user tests, are often at odds with the agile development methodology commonly used in entertainment gaming: rushing a prototype to meet a deadline for user testing can often result in feedback which could be anticipated. Secondly, participatory design is a term often used relatively loosely: in the case of PEGASO, three focus groups conducted on three sites (n∼10–15 per site), at approximate 3-month intervals, gave users the chance to write and discuss ideas for future development but could be argued as limited in terms of overall participation in the 2-year design and development cycle. In summary, De Smet's findings are clear, though perhaps reflect how difficult participatory design is to enact meaningfully in a large-scale serious game project, rather than a failure or irrelevance of participatory design methodology.

In summary, the PEGASO project and associated game development have accommodated theoretical aspects, deriving mechanisms via the COM-B model (Michie et al. 2011) in synergy with entertainment game design. Most significant of these is an attempt to align the "microtransaction" model common to entertainment gaming with health behaviour theory, to instead seek to induce behavioural transactions. Noting the need for engagement, the project illustrates how key entertainment mechanics of narrative, exploration, combat, and crafting can be synergised with serious objectives. From a research standpoint, whilst barriers to effective iterative and participatory design exist as noted above, user trials have allowed for key focus areas to be elicited through discussion with end users. An overall effectiveness trial of the PEGASO system, including the game, is forthcoming; findings will no doubt inform the development of this and other interventions, as well as aiding in validating and identifying issues with the overall approach.

## 15.6 Conclusions

Games that encourage and support healthy lifestyle behaviours can impart knowledge and learning in a fashion which empowers the player, motivating them to overcome challenges that impact upon their life in a meaningful way. As outlined by this chapter, examples of successes in the area exist, and as an entertainment medium, future focus on serious uses of games in the area has clear merit. However, achieving successful impact requires a range of factors to be considered, including how best to accommodate the ability level of every player, identify and improve their knowledge and skills, and relate outcomes to their needs and values. This in turn requires affordances during both project setup and design to enable effective inputs from theorists, researchers, and game designers.

Drawing from the authors' collective experience on a range of large-scale projects, this chapter has outlined some common risks and mitigation strategies when seeking to implement a multidisciplinary approach. The PEGASO approach to game design and evaluation has provided valuable insight into tackling these risks in practice, particularly when aiming to enable serious games and affiliated technologies to be embedded in such a way that they pervade aspects of the target user's everyday life. It has also sought to further balance behavioural theory with entertainment, drawing on abstraction to create a "zombie apocalypse" whilst reflecting a behavioural framework and iterative approach to design. However, challenges still persist when seeking to fully address these risks. Project teams containing the breadth of expertise required are seldom co-located, heightening risks associated with communication; project structures and timeframes are often planned in advance, making agile "as needed" approaches to user feedback challenging; and tensions remain around whether a game should, foremost, be "fun".

Future solutions to the issues faced may come from a range of sources. The business model itself for serious gaming remains largely projectised and at odds with the entertainment industry. Providing a serious game as a constantly refined and updated service, rather than a singular product, would enable a greater degree of iteration and testing "in the wild". This would, in turn, capitalise on the benefits of analysing user data over time to identify behaviours and trends, a practice widespread in the entertainment gaming industry yet comparatively rare in a serious context. The emergence of serious games as a discipline is also contributing to the formation of a community with a greater shared knowledge of the various disciplines and skills involved, aiding in communication and understanding throughout project life cycles. Evaluated examples of serious games number in the hundreds, with the vast majority less than a decade old (Connolly et al. 2012). As the evidence base continues to grow, deeper and more specific understanding of design challenges, and evidence supporting low-level decisions, will further contribute to the growing field.

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# Chapter 16
# Digital Games in Early Childhood: Broadening Definitions of Learning, Literacy, and Play

**Marja Kankaanranta, Merja Koivula, Marja-Leena Laakso, and Marleena Mustola**

**Abstract** Digital games attract children and young people with imaginary worlds, fascinating stories, and shared experiences with peers. They also can add children's learning and motivation and offer a variety of new affordances to explore and play with. The pedagogical use of digital games has been found to potentially intensify a more critical use and understanding of varied forms of media. In this chapter, we will focus on analyzing the role of digital games in early childhood, especially from the perspectives of learning, literacy, and play. This chapter examines digital games as playing an essential role in young children's overall technology experiences, particularly in the context of the social dynamics of families and children's other close communities. In our mind, the analysis of young children's learning while they are engaged in digital games in informal contexts furthers our understanding of the potential of game-based learning in formal early childhood education settings.

**Keywords** Digital games • Early childhood • Learning • Literacy • Play

## 16.1 Introduction

Digital games captivate children with imaginary worlds, fascinating stories, and shared experiences. According to Jenkins et al. (2006), it is through digital games that children learn how to play, perform, express themselves, and collaborate in various communities in which they participate. Digital games can at best contribute to children's learning and motivation and offer a variety of new affordances to explore and play with (Stephen and Plowman 2014). There is also growing evidence that shows the importance of giving digital games and game playing a significant role at educational settings as part of the curriculum and ICT-enhanced practices (e.g., Dillon 2004; Jenkins 2006; Stephen and Plowman 2014). Children are adept at

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learning new content through digital game playing, as has been revealed by studies in which digital games have been used in the classroom.

Digital technologies, in general, have become an integral part of children's daily lives (Chaudron 2015), and in many countries, children are growing up in media-rich homes. For example, in the UK, nearly 90% of children aged 5–6 use computers or tablets, and around 70% use the Internet (Livingstone et al. 2015). This chapter examines digital games as playing an essential role in young children's overall technology experiences, particularly in the context of the social dynamics of families and children's other close communities such as day care and school. The earlier research literature on the role of digital technology in early childhood emphasizes the need for a comprehensive understanding of practices and interactions in children's technology use within a wider learning context or ecology (Alper 2011; Burnett 2010; Jenkins et al. 2006).

Despite the advancement in the fields of game-based learning, the attractiveness of *learning games* and the level of engagement and flow they provide are generally far below the engaging flow offered by the commercial digital games designed for entertainment. Contradictory to the playfulness of young learners, games developed for educational purposes are mostly trivial in nature, being much less attractive to children, and thus discourage individuals who are familiar with more challenging and immersive games from a physical, cognitive, emotional, and social perspective (e.g., Charsky 2010). Many contemporary games have either been developed without appropriate pedagogical principles or lack typical game features (Kiili 2007), even though there are emerging guidelines and considerations for the design of developmentally appropriate games for young learners (Peirce 2013).

In this chapter, we will focus on analyzing the role of digital games in early childhood, especially from the perspectives of learning, literacy, and play. The problem is that even though games are, for the younger generation, a distinct form of informal ICT literacy practice, their pedagogical use in early childhood education varies, and their educational potential is not always fully realized (Buckingham and Burn 2007; Kankaanranta 2007a; Peirce 2013). In our mind, the analysis of young children's learning while they are engaged in digital games in informal contexts furthers our understanding of the potential of game-based learning in formal early childhood education settings (see Lai et al. 2013; Voogt et al. 2013) as well as how formal, nonformal, and informal learning can be bridged.

Overall, game development for children, especially for very young children, is still globally an emerging market with only about 8% of the market share of the game industry (Peirce 2013). However, digital games comprise a fast-expanding field, and no other sector has experienced the same explosive growth as the computer and video game industry. A survey of the Apple App Store Education category indicates that in 2014, 60% of educational game apps were targeted toward ages 5 and under, 29% toward ages 6–8, and 11% toward ages 9–11 (Peirce 2013). On the other hand, there is still scarce research evidence concerning young children and the use of digital technology in educational settings (Chaudron 2015; Stephen and Plowman 2014).

## 16.2 Learning in, Through, and Beyond Digital Games

This section explores the relationship between digital games and learning in order to broaden the way we think about game-based learning. In the first volume of *Serious Games and Edutainment Applications*, Mitgutsch (2011) determined that players learn in three levels: in games (e.g., through the content, topic, and narratives in the games), through playing games (e.g., through rules and goals of the game), and beyond games (e.g., changing players' perspective about themselves, others, and the world). The transformative learning process that Mitgutsch describes is close to our purpose of better understanding the ways learning can be seen: not as restricted but as a multidimensional process.

In western cultures, there has been a shift toward lifelong learning within the discourses of advanced liberalism and knowledge economies. Key competences for lifelong learning in the contemporary educational discourses seem to be deep engagement and positive attitude toward learning (Ailwood 2008; Binkley et al. 2012; Buckingham Shum and Deakin Crick 2012; European Communities 2007). It is not surprising that digital games show up in these same discourses, since they have been proposed as an excellent way to motivate learners (e.g., Prensky 2001). They have become an extremely popular subject in the field of education, mostly due to the fact that children from early on appear to be extremely attracted to playing and interacting with various kinds of digital media. A central question is: how useful are such digital games for teaching and enhancing deep learning among children? In order to draw conclusions on the effectiveness of digital games for promoting desirable learning outcomes, it is necessary to carefully evaluate the central factors affecting learning and the content design of the games.

### *16.2.1 The Elements of Motivation, Autonomy, Competence, and Relatedness in Digital Games*

There are numerous theories on learning. Given that our goal is to broaden the concept of learning in the context of playing digital games, we specifically concentrate on the interfaces of learning and motivation. One of the most used and cited theoretical concepts for understanding human learning is the concept of *intrinsic motivation*, originally introduced in the 1950s (White 1959). This natural motivation tendency is considered an important element in learning and development, since individuals are more likely to expand their knowledge and skills when acting upon their inherent interests (Ryan and Deci 2000). This inclination to use one's skills creatively is present in very young children but also detectable throughout the whole human life-span. Such intrinsic motivation exists in the relation between individuals and activities (e.g., Deci and Ryan 2000). People are intrinsically motivated for some activities and not for others. These conceptions of motivation helped investigators to determine the task characteristics that make any activity interesting.

In line with Connolly and his colleagues (Connolly et al. 2012), the most frequently mentioned positive effect of games on learning is increased motivation, which is often lacking among children who find traditional education challenging. In their broad-based social theory on motivation and personality, the so-called self-determination theory (SDT), Deci and Ryan (2000) argue that an activity is intrinsically motivating if it satisfies the basic psychological needs of human beings. According to SDT, these innate needs are autonomy, competence, and relatedness. So, when evaluating and reflecting on the educational value of digital learning games for young children, the SDT offers one potential theoretical framework to apply.

The basic *need for autonomy* and the intrinsic motivation for activities that support this need in young children are clearly seen in their state of deep absorption, for example, in free play with toys, with other children, and with various natural or artificial materials. Free play represents an activity that is freely chosen and offers freedom of choice and opportunities for the creative use of one's skills. A vast majority of researchers acknowledge that the most prevalent benefits of digital games are their ability to motivate and engage children (Erhel and Jamet 2013). It is no wonder then why digital game-based learning—specifically gameplay, which is used as a primary tool for learning—has been proposed as an excellent way to offer educational contents and promote knowledge learning (e.g., Prensky 2001).

Digital games are examples of user-centered designs that give the children the power of ample expression and motivation through arousing interest (Iten and Petko 2014), and thus they can be regarded as fulfilling the basic need for autonomy. However, the examples with school-aged children (see Ronimus et al. 2014) show that enjoying the game was insufficient to ensure persistence and sustained engagement in educational learning games. In addition, showing flow while playing did not necessarily affect the learning outcomes of high school students (Admiraal et al. 2011). It appears that merely providing an activity that is intrinsically motivating for the children does not guarantee successful learning outcomes. Hence, further research is required in order to identify the kind of engagement the game should provide in order to accomplish the learning goals.

The other psychological need, *need for competence*, refers to the experience of effectiveness in carrying out a particular activity (White 1959). It has been said that digital games support engagement and motivation because they offer constant challenge and feedback to the players (Sweetser and Wyeth 2005). In the study by Inal and Cagiltay (2007), the flow experiences of 7- to 9-year-old children were studied in a social game environment. The study found that for the majority of the children, the most rewarding element of the game was the *challenge*. So, the games that include various challenge levels and immediate feedback seem to be the most effective for producing flow experiences. Yet, as mentioned, a flow experience is not the same as being engaged with the process of deep learning (see Erhel and Jamet 2013).

An essential factor here in analyzing learning in gameplay is the active investment in information processing, also called the cognitive load that the child invests in gameplay. If the game is too difficult and the cognitive load too big, the game fails to provide experiences of success for the player, and hence the need for competence is not fulfilled (e.g., Sweetser and Wyeth 2005). However, if the instructions or the given feedback supports the player to actively invest in playing (e.g., employ high-quality cognitive processing and strategies), meaningful learning is expected as a result. In the case of young children, it is probably even more important that the significant adults around give him/her encouraging feedback and acknowledge his/her efforts.

With regard to need for competence, one typical factor in digital games, which provides both challenge and motivation, is the element of *competition*. This might happen between the player and other players or when the player is competing with her/himself to attain better scores for solving problems, completing tasks faster, or collaborating successfully (see, e.g., Inal and Cagiltay 2007; Prensky 2001; Sweetser and Wyeth 2005).

The last of the three psychological needs is the need for *relatedness*. This concept refers to a sense of connectedness with significant others. This is also a very critical aspect, since one of the most often stated risk factors of digital playing relates to the social disconnectedness of playing. There is a fear that playing has negative impacts on children's social relationships. Playing is stated to be unsocial and disconnecting the children from real-life interaction and social relationships. However, studies have indicated that young children's digital gameplay activities are often in fact social, since they contain peer interaction, social interaction between humans and machine, and games that include social objects (e.g., Mustola et al. 2016). There are also digital games that train social competences (see Koivula et al. 2016). Children can, for instance, exercise their mind by putting themselves into a simulation of real-life social situations. So, when we consider the educational significance of a digital game, one crucial feature to reflect on is its social value, e.g., the kinds of interaction opportunities, strategies for solving social problems, and models for social behaviors that it fuels.

Examining the intersections between learning and the fulfillment of basic psychological needs offers one way to understand learning with digital games. Nevertheless, it is not the only way to consider learning in our digitalized society. There are several disciplines and discursive strands involved in a way learning in, through, and beyond digital games is conceptualized (see Mitgutsch 2011), which we will explore next.

### *16.2.2 Early Childhood and the Learning Potential of Digital Games*

The pedagogical use of digital games has been found to potentially intensify a more critical use and understanding of varied forms of media (e.g., Dillon 2004; Jenkins 2006). It has also been shown to diversify the ways that information and communication technology is utilized at schools and the ways that schools help students to become digitally competent and ethical citizens of the information society (e.g., Kennewell and Morgan 2006). At best, digital games provide rich, fun, and interactive experiences that contribute to young children's learning and social interactions (Lieberman et al. 2009). However, despite the emergence of research in this area, what children actually learn through playing digital game remains a key issue.

When we discuss learning through digital games, the current *developmental stage of the child* that forms the basis for learning also becomes relevant. As Plowman (2016) highlights, there exists a variety of skills, dispositions, and competences that a child learns during 1 year of life, and therefore, only generalized statements can be made about the influence of children's developmental stage on the use of technologies. First of all, children need certain fine and gross motor skills in using technology, including swiping a touchscreen or pressing keys, and these become possible after learning movement control. Cognitively, many digital games presume skills like understanding simple rules, making choices, or sorting. These skills develop around the ages from 4 to 6, and through learning the skills needed, an array of new digital gaming opportunities becomes available for children. Also, in the same age period, children grow more independent, begin to control their behavior and impulses, and understand different rules; these abilities have also impacted their gameplay experiences. Furthermore, the visual aspects of the game, storylines, and the humor in many games appeal to children's senses and make games even more attractive, though it is necessary to recognize that children respond to games individually and age dependently.

However, in the literature, the emphasis seems to be more often on the technology than on learning (Plowman 2016), and there is a paucity of research concerning technology-mediated learning of children under the age of 7. Connolly et al. (2012) identified the most frequent outcomes of game playing of children age 14 years or older to be affective and motivational as well as knowledge acquisition or content understanding. These were followed with effects related to perceptual and cognitive skills, behavior change, physiological outcomes, and social/soft skills outcomes. However, for the age group of this chapter, i.e., children under the age 7, these areas of learning are supposedly somewhat different. It can be assumed that the affective and motivational dimension or content understanding as the most frequent outcomes of gameplay applies also for this younger age group. However, it should be acknowledged that young children learn many things through imitation and observing the use of technologies by their parents, siblings, or more competent peers (Plowman 2016). Together with teachers and peers, children learn to interact with ICT and become competent users of new technologies, as revealed by Kennewell and Morgan (2006).

In addition to informal learning of technology, it is necessary to look at the pedagogical practices and how different games are utilized in the educational contexts. Games are not yet frequently used in learning and its assessment, even though during the last few years, the development in this area has been exceptionally fast. With regard to curricular subjects, positive effects have been reported in areas such as language and literacy learning, history, and physical education (Kankaanranta 2007a; Young et al. 2012). As an example of acquiring cross-curricular skills, digital games can provide opportunities to learn skills such as self-expression and collaboration (Jenkins 2006), critical use of varied forms of media (e.g., Dillon 2004; Jenkins 2006), and other digital competences (e.g., Kennewell and Morgan 2006). Game-based learning has also been found to be a good way to support learners with disabilities (e.g., Pivec 2007), as well as migrant children and youth in identity formation (Kankaanranta 2007b). As for young children, games have found to support the development of skills such as phonological awareness, memory enhancement strategies, motor skills, and coordination (Peirce 2013).

We should still acknowledge that positive effects of technology on learning are not, however, automatic. In particular, the effects of game-based learning for traditional academic achievement of subjects such as sciences and math have been questioned (see Young et al. 2012). In the review of studies focusing on learners ages 4–19 (Young et al. 2012), authors found only some effects of video games on language learning, history, and physical education but only little effect on learning science and math. There are also claims about the negative effects of games for learning and development (e.g., Lieberman et al. 2009; Plowman 2016; Singer and Singer 2005; Stephen and Plowman 2014) such as detracting from cognitive, practical, social, emotional, and psychomotor development. Some of the most frequent claims are related to increased aggressiveness, antisocial behavior, and obesity (see Mishra and Foster 2007; Peirce 2013). Especially, when considering young children, the discussion tends to turn out even more critical and emphasize the possible negative outcomes of digital technologies (Palaiologou 2016). These notions articulate the challenges related to the effective use of games for educational purposes and call for more detailed research on the processes of game-based learning and digital games on both learning and development. Peirce (2013) emphasizes that in addition to common game-based learning challenges, the design of educational games for early childhood necessitates the consideration of more specific issues. The most crucial factors relate to the developmental level of the learners, including the pedagogical approaches and learning tasks reasonable for young children.

In other words, we need to gain an understanding of what makes game-based learning a productive, enjoyable, and rewarding experience. It is suggested that from the perspective of children, although they find many digital games intriguing, available learning games are often less attractive than entertainment games. In addition, we require more knowledge about the qualities of different games that support children's learning and participation. In particular, we are lacking research that examines specific features of educational games that support engagement and promote deep-level learning by providing a meaningful learning context. We still need to address questions like what type of instruction and feedback do successful educational games provide, what specifically occurs in the gameplay situation (e.g., presence, involvement, and dialog with peers/teachers/parents), what kind of game design motivates children to learn through gameplay, and how the game design and contents align with the curriculum.

## 16.3 Toward Multiple Literacies

This section explores the relationship between digital games and children's literacy development and practices. We start by discussing the widening definitions of literacy and then analyze current understanding of the effects of digital games on young children's literacy learning and practices.

### *16.3.1 Digital Games and Multiple Literacies*

Young children's digital learning opportunities and their role in overall literacy development are rapidly piquing interest in academics and also among general public. At increasingly earlier ages, children today encounter various digital media that offer them opportunities to discover diverse digital texts. Young children are nowadays coming to early childhood education environments with a different set of literacy skills, with experiences of more diversified possibilities for learning and literacy than previous generations, and also with more diversified access to possibilities of digital technology (Alper 2011; Blanchard and Moore 2010).

There seems to be a number of definitions and concepts through which digital games are connected or associated with literacy. Digital games are generally characterized as multimodal texts that employ a range of strategies that contribute to new forms of literacy. As multimodal text, they combine text, still and moving images, sounds, movements, and bodily sensations and necessitate the use of different communicative means (Gee 2003; Buckingham and Burn 2007; Marsh 2002). They also present children broader elements, such as narratives in which they can be actors and producers by carrying out actions of the game characters (e.g., Marsh 2002). Burnett (2010) underlines the need for using a broader gaze for understanding children's interactions with digital texts, as they offer them new opportunities to engage with multiple contexts.

Existing research literature focuses on explaining the relationship of literacy to young children's comprehensive technology use, and digital games are considered part of young children's digital world (e.g., Blanchard and Moore 2010; Burnett 2010). The current frameworks on the relationship of digital games and literacy are generally conceptualized around older children and young people. Blanchard and Moore (2010) remind us that they continue to build valuable understandings about the digital media environments that surround young children as they develop emergent literacy skills. Nevertheless, the more specific evidence-based understanding of the effects of digital game playing on the literacy development and practices of young children is limited, and its impact on young children's literacy development is still largely unknown. The following section seeks to ground the conception of the relationship between digital games and literacy on the studies that seek to understand the effects of digital media or technology on literacy development and practices as well as on the studies focusing on older age groups.

As Plowman (2016) highlights, a strand of research, usually based on experimental designs, compares traditional reading-to-reading practices on screen. Miller and

Warschauer (2014) suggest, based on their literature review, that there are certain features in digital books that engage children and promote literacy (e.g., font size manipulation, dictionaries, automatic page turning, and animation hotspots), but there exists also hindrances like too much animation, which draws attention away from the text. Moreover, Miller and Warschauer (2014) assert that printed books and e-books seem to play different roles in the literacy process, thereby offering children also different literacy experiences.

The frameworks on the relationship of digital games and literacy generally highlight that development in computing contributes to wider or even entirely new forms of literacy or that digital game playing demands specific literacy skills that overlap with skills utilized in interactions with printed texts (e.g., Alper 2011; Blanchard and Moore 2010; Marsh 2002). Dillon (2004) locates this discussion within a wider reevaluation of the nature and purpose of literacy in contemporary media-rich societies. Lankshear and Knobel (2006) distinguish two ways that new technology affects textual practices, firstly, through replicating practices associated with print text or so-called old literacies and, secondly, by being associated with "new literacies," patterned by distributed relationships, multiple identities, multimodality, and global participation. Mateas (2005) mentions yet another skill, namely, "procedural literacy," as necessary for utilizing computational media such as digital games in school literacy curricula. He defines procedural literacy as the ability to read and write processes, to engage in procedural representations and aesthetics, and to understand the interplay between the culturally embedded practices of human meaning-making and technically mediated processes.

Kress and Van Leeuwen (2001) widen the definition of being literate from having the ability to create and interpret traditional forms of literacy, such as reading and writing, to engaging with multiple representations often at one time. Digital games finely exemplify this combination of written, visual, audio, and gestural modes of communication. Buckingham and Burn (2007) seek to combine social semiotic approaches on how young people make meaning with media authoring tools together with cultural study perspectives, exploring the cultural experiences and practices that inform such creative work. Their goal is to build a theory of game literacy, which addresses both the representational and the ludic dimensions of games. The theory addresses not only the critical and functional but also the textual dimensions of games. Moreover, it recognizes the social contexts and social processes through which literacy is manifested and developed. According to Sánchez-Navarro et al. (2015), the concept of ludoliteracy refers not only to video games, or to what is explicitly understood as a game, but also to the current tendency of the digital society toward playfulness in the form of ubiquitous games on mobile devices and the increasing gamification of art, marketing, and social media.

In summary, there are several different ways to conceptualize how digital games relate to and affect literacy. Game playing can alter traditional literacy, especially the ability to read, and also our common understanding of literature as text. At the same time, however, games can teach new literacies, which shape the way people communicate. Digital games are creating a new form of literacy with varied visual character interactions and oral means of communication. This necessitates expanded definitions of literacy. Digital games can also generate literacy. This has to do with the different literacy practices that the gaming communities participate in by reading and writing game reviews and rankings and by building community websites to share game histories, ideas and information about games they are attracted to or captivated by.

### *16.3.2 Multiple Literacies in Early Childhood*

According to Blanchard and Moore (2010), children's exposure to digital media clearly affects their emergent literacy development and provides multiple emerging literacy learning opportunities outside formal early childhood environments. The quality and quantity of children's opportunities to develop and use emergent literacy skills, including digital literacy, has a critical role in laying a foundation for their language use and thinking skills in adolescence and adulthood as competent citizens in the digital globe (Hillman and Marshall 2009). On the other hand, Mavers (2007) asserts that engagement with digital texts is valuable for children's current lives, and young children are already rather than just becoming literate. Alper (2011) continues in this same vein, highlighting early childhood as a phase of life with its own value and young children's active role as consumers, creators, and distributors of media, tools, and technology.

McTavish (2009) argues that children may differentiate between literacy practices at home and formal educational settings and even sustain separate "literate lives" within and beyond these settings. Also Levy (2009) raises concerns of the negative impact of such contrasts on young children's literate identities. Moreover, Hashemi and Cederlund (2016) note that research on digital technology in early literacy learning and teaching is still rather scarce and has a focus on children's engagement with digital texts and on the use of new technologies as tools to support existing literacy provision to develop print-based literacy (see also Burnett 2009). Thus, there is a need to address such possible discontinuities in children's literacies and to gain better understanding of the role of new technologies in early childhood practices and about the dimensions of young children's interactions with technologies (Alper 2011; Burnett 2010; Hashemi and Cederlund 2016). According to Alper (2011), understanding of young children's media literacy necessitates an exploration on all the materials with which they work, learn, and play.

Burnett's (2010) research review into technology and literacy on children ages 0–8 in educational settings resulted in three categories that positions digital technology (including digital games) as (1) a deliverer of literacy, (2) a site for interaction around texts, and (3) a medium for meaning-making. Similarly, Hashemi and Cederlund (2016) specify a relation between literacy and digital technology into three components, namely, digital technology as a means and resource for developing literacy acquisition, as a competence area that has an intrinsic value, and as broadening literacy development.

Through exploring the links of a new media literacy framework (NML framework; Jenkins et al. 2006) for early childhood education, and especially for Reggio Emilia pedagogy, Alper (2011) tracked several theoretical and practical ways in which this NML framework implicitly and explicitly addresses early childhood education. She emphasizes that its basic concepts (such as simulation, collective intelligence, and multitasking) are familiar, yet not named similarly, to early childhood education, and many of the 12 core media skills are, indeed, already an integral part of early childhood philosophies and curricula. The most distinct links relate to the learning theories, the effort to understand each child's learning and communication ecologies, and the focus on partnership between home and children's learning environments. Out of the 12 core media literacy skills, Alper (2011) focuses on play, distributed cognition, and transmedia navigation. In the NML framework (Jenkins et al. 2006), play is conceptualized as the capacity to experiment with one's surroundings as a form of problem solving. Distributed cognition refers to the ability to interact meaningfully with tools that expand mental capacities and transmedia navigation as the ability to follow the flow of stories and information across multiple media. Similarly to Jenkins' (2006) accentuation of the relationship between digital games and children's play, Burnett (2010) has observed that the studies of young children's interactions and engagement with digital texts in informal settings highlight playfulness, agency, and creativity.

## 16.4 The Significance of Digital Play

In this section, we set out to explore the features and significance of digital play with games for young children. The issue around digital play seems to be, at least partly, a contested area. The literature review reveals that the discussions around digital play seem to be polarized: there are claims that technologies both enhance and inhibit children's development and learning (Stephen and Plowman 2014). While some see technology as an integral part of children's play and learning (Jenkins 2006; Koivula and Mustola 2015; McClure and Sweeny 2015; Mustola et al. 2016), others express concerns about technology causing passivity and preventing children's play and development (Blum and Parette 2015; Stephen and Plowman 2014).

The whole issue of young children's play with technologies seems to evoke emotions, and easily leads to discussions in which the arguments are not evidence based, but rather comprises of personal opinions and emotion-based conceptions. More research is required on what kinds of affordances (e.g., for creativity, play, and imagination) technologies produce for children's play and in what kinds of ways children incorporate these in their digital play practices (Stephen and

Plowman 2014). Additionally, Erhel and Jamet (2013) state that the approach where we compare learning outcomes achieved through digital media against the ones achieved through conventional media is vulnerable due to many confounding factors (e.g., format, context, and teacher's presence). A more fruitful approach would therefore be to focus on identifying factors that enable or promote learning within the digital play context.

### *16.4.1 Defining Digital Play*

There exists a paucity of research to date concerning the role of digital games in children's play. Exploring play has proven to be a challenge, since the very concept of play is inherently complex and elusive (Grimes and Feenberg 2009; Marsh 2010, 2014; Stephen and Plowman 2014). Furthermore, there is a lack of consensus about the definition of digital play. Here, we are using the concept "digital play" in referring to a range of activities in children's technologically mediated play. Others (e.g., Edwards 2014) prefer the term "contemporary play," which is considered to include both technologically mediated play and traditional play without technological aids. Moreover, in the field of game studies, concepts of "gamification" (e.g., Tulloch 2014) and "ludification" (e.g., Grimes and Feenberg 2009; Kapp 2012) inform new perspectives on the phenomena. Despite the variation in the use of these interlinked concepts around the phenomena of digital play, it is clear that exploring digital play has turned out to be challenging. There is no clear-cut boundary between play and gameplay (Marsh 2014). Therefore, we should gain an understanding of the different ways children are combining games and play and the different affordances available for their digital play.

For children, play can occur almost everywhere, and almost anything can turn out to be play (Glenn et al. 2013). Children learn when they play and through play. Play also molds and mediates children's relationship to technology. In children's daily lifeworld, play and gameplay have grown closer to each other. One manifestation of this is "hybrid play" in which the technology is combined with traditional toys or play affordances (e.g., Marsh et al. 2016; Plowman 2016). The same applies to games: they bring together playful elements of "traditional play" to the context of gameplay. As stated before, the element of autonomy in games seems to be important for children: they are the ones who determine, how to transform, develop, employ the affordances provided by the game (see Gergen 2015), and, thus, construct their own digital agency.

Yet the issue of digital play is related to educational or serious games as well. Children can invent new, creative, and more playful ways of combining the different elements of the game into their play (see, e.g., Marsh et al. 2016). When we gathered empirical data from children's gameplay, we observed a variety of different possibilities that children were utilizing in digital play (see Koivula and Mustola 2015; Mustola et al. 2016). For example, children adopted play roles related to gameplay and the events of the game, they took themes and ideas from the game and utilized them in their traditional play, and they imagined contents of the game, took videos with tablets from their traditional role play, and performed scripted movie trailers from play situations. Furthermore, children wanted to design new digital games themselves and began to draw them on paper collectively (Koivula and Mustola 2015). These examples clearly show how children's hybrid play can appear in numerous forms.

### 16.4.2 The Educational Value of Digital Play in Early Childhood

Our empirical data suggests that the quality and interest value of the digital game influence the gameplay activity and the ways that children's digital play evolves. In many cases, children became emotionally attuned to games that offer possibilities to utilize one's own creativity, include "open" layout instead of fixed options, and contain different elements (e.g., characters and events) that appeal to them and create a possibility for immersion (see Ermi and Mäyrä 2005; Frissen et al. 2015; Mallon and Lynch 2014). In digital play, children interact with each other, with the game, and with technology (Kalaš 2010; Salonius-Pasternak and Gelfond 2005). In addition, children's digital play does not necessarily presume a face-to-face interaction with a partner, but digital online social interactions have grown more typical among children (Chaudron 2015; Livingstone et al. 2015; Marsh 2010). These abovementioned aspects represent the qualitative and unique features of digital play and differentiate them from "traditional play" (Salonius-Pasternak and Gelfond 2005).

In digital play, children are able to adopt new kinds of roles, experience adventures, and expand their imagination in a new way, because the digital games offer possibilities and guidance for this in their layout. Moreover, digital play is at many times social: the children play together, create solutions, construct knowledge, and create their own, unique digital play culture. This is linked to redefining, molding, and shaping their personal and social group identity and adopting and practicing different roles during their gameplay (Arnott 2013). Children move fluently across different spaces and contexts of play and combine the elements of different forms of playing, i.e., virtual and traditional, together (see Craft 2011). From the perspective of children, the boundaries between digital play and traditional play are artificial and irrelevant. As stated before, for children, anything can turn out to be defined as play (Glenn et al. 2013). Therefore, to understand the complexity of play and digital play requirements, constant interplay between children and peers is necessary, as digital play is a social construction that is created during joint activity (Craft 2011; Marsh 2010). From a research perspective, this presumes close examination of digital play, defining the criteria for digital play, and the effort to explore digital play across different contexts and among children of different ages.

In our mind, through empirical research, it is possible to understand the benefits and possible risks related to children's play with technologies.

The examples presented above illustrate the ways that children participate in the practices of digitalized society and how digital games offer a variety of possibilities and resources (see Arnott 2013). The input of children has grown more important as co-researchers, for instance, testing new products in the game industry (Lieberman et al. 2009). This is why the understanding of digital play is becoming more and more topical. As the theoretical discussion suggests, digital play and hybrid play must be considered as more than merely a threatening opposite of traditional play.

## 16.5 Concluding Remarks: Toward a Child Perspective on Digital Game Playing

> *The tangible nature of some of the technologies can support young children's play and learning, and the multimodal nature of feedback may have some impact on children's movement, cognition, and emotions; at the same time, cultural and social change within the family and the wider community will influence patterns of play. (Plowman* 2016*, 109)*

Our exploration on the role of digital games in early childhood proceeded through the perspectives of learning, literacy, and play. The review of the research literature in each of these perspectives indicates distinct polarities or tensions regarding the relationships of young children with digital games or, more generally, with varied digital technology. Such tensions seem to exist between, e.g., a child and teacher, home and early childhood education settings, intentional and unintentional learning, and digital and non-digital practices as associated with the relevance or role of digital games as young children's practices. However, when considering these tensions from a child's perspective, it becomes clear that it is not a question of tension for a child, but rather digital games and digital game playing appear as a natural part of children's various daily activities, especially in informal contexts such as at home or in interactions with peers.

Many of the tensions relate to the use of digital games for educational purposes in early childhood learning environments. Previous research has raised concerns regarding the established beliefs and attitudes of teachers about digital games and their integration in the teaching-learning process. Even though games are, for the younger generation, a distinct form of informal ICT practice, they are still not very frequently used in early childhood education (Buckingham and Burn 2007; Mediappro 2006; Plowman 2016; Rideout et al. 2010). However, during the last few years, tablets in particular have become more common in the context of early childhood education. These mobile devices—thanks to their light weight, portability, and affordability—offer new pedagogical opportunities, especially for children, e.g., for multimodal learning (Plowman 2016).

The existing gap between the children's conception of digital games and gaming and those held by teachers is at least partly attributed to teachers' digital skills, as learning to use digital technology usually requires many teacher particular efforts.

Another central issue is that the pedagogical use of digital technologies tends to divide teachers (Plowman 2016). Koivula (2015) found out in her study that there existed polarized opinions about the use of technologies in preschool. Some teachers emphasized the learning potential of digital technologies and used, e.g., tablets in their teaching innovatively. For example, they used digital learning games, made documentation with tablets, created QR-code assignments for children, and made movie trailers as a joint project (see also Marklund and Dunkels 2016; Plowman 2016). The positive attitude of these teachers allowed children to explore the possibilities of these devices quite freely and thus promoted the children's technological agency and skills. The majority of teachers in Koivula's (2015) study had this kind of positive outlook on technology in early childhood education, and they appreciated the new contents and possibilities that technologies offered children, viewing these devices as an integral part of children's daily lives.

Nevertheless, some teachers were concerned about the pedagogical use of technology in preschool (Koivula 2015). Their attitude toward new technology could be described as suspicious. Typically, they lacked confidence about their own skills as users of digital technologies. These teachers restricted children's activities to digital technologies (e.g., seldom permitting them to use tablets or only for a short while) and expressed concerns about the negative effects of digital gameplay on children's "traditional" play and learning (see also Marklund and Dunkels 2016; Plowman 2016). Koivula (2015) asserts that the attitude of the teachers on the whole seemed to depend on the amount of training they received. Generally, the teachers emphasized their need for a lot of training for the pedagogical use of digital technologies. In addition, getting oneself familiarized with new technology required time and effort. In the pedagogical use of digital technologies, teachers also seem to need a great deal of support from their colleagues (Marklund and Dunkels 2016).

The apparent changes in children's everyday world necessitate a reexamination of the educational practices and curriculum, as knowledge, learning, and relationships are being redefined in digital environments (Burnett 2010; Marsh 2002). An up-to-date curriculum helps children to become competent and fluent users of various digital media, particularly of digital games, and the increasingly complex multimodal texts surrounding them. It would also bridge children's digital practices at homes with early childhood education environments (e.g., Burnett 2010; Kankaanranta 2007a). Early childhood settings should therefore take into account children's informal learning experiences and build upon them.

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# Part VI
# Serious Games for Serious Topics

# Chapter 17
# "Walk a Mile in My Shoes": A Virtual World Exercise for Fostering Students' Subjective Understandings of the Experiences of People of Color

**John Tawa**

**Abstract** In the virtual immersion project (VIP), students in the author's Cross-Cultural Psychology class spend 2 h interacting in the virtual world, Second Life (SL), while piloting an avatar of a different racial background from their own. A qualitative coding of students' ($N = 16$) reflection papers related to the VIP suggest that the project facilitated students' complex understandings of race and racism, both affectively and intellectually. For example, some White students described feelings related to experiencing racial microaggressions while piloting avatars of color and related these experiences to their developing understanding of the concepts of race and their own White privilege in real life. Some students resisted seeing the role of race in their interactions. These findings are discussed in relation to the potential for the VIP to facilitate social justice educators in meeting the goals of transformative education pedagogy.

**Keywords** Virtual world • Second Life • Racial experiences • Empathy • Transformative education

## 17.1 Introduction

In 1961, John Howard Griffin, a White author, published *Black Like Me*, chronicling a six-week journey through the Deep South passing as a Black man. The experiences of racism that Griffin faced were transformative for him in that he was able to gain a subjective understanding of the racial experience of being Black in the USA (Griffin 1961). Although a White student may be able to intellectually grasp the concepts of racism and racial microaggressions, it may be more difficult to understand the emotional experiences associated with being slighted or treated differently because

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of one's ascribed status as a racial minority. Thus, social justice educators seeking to foster transformative educational experiences, within constructivist pedagogy, frequently employ class exercises designed to help students in positions of privilege access experiences of oppression from a more subjective perspective (Plous 2000; Suyemoto et al. 2009; Yeung et al. 2013). For example, students may be provided with scenarios of incidents of overt prejudice and then asked to take turns role-playing as victims, bystanders, and perpetrators of incidents (Plous 2000).

Recently the author of this paper has conducted an exercise in his Cross-Cultural Psychology classes that uses virtual world technology to enable students to participate in social interactions as a member of a racial background different from their own, with the goal of fostering students' empathic and subjective understandings of the experiences of people of color. This paper provides a qualitative analysis of students' reflection papers written after completing the virtual immersion. Although this initial program evaluation warrants further, more rigorous empirical investigation to confirm its effectiveness, the challenges and themes arising from this preliminary analysis should be useful in that they provide researchers with specific directions of inquiry and educators with both a rubric for conducting this exercise as well as specific challenges they may face.

The virtual immersion project (VIP) is designed to increase students' awareness of the *racialized* experiences of people of color, including the ways in which members of racial groups falling under the umbrella of people of color (e.g., Blacks, Asians) are treated socially as a result of expectations related to stereotypes. This project is not intended to increase students' awareness of the various *cultural* experiences of members of cultural groups falling under the larger umbrella of people of color (e.g., Japanese, Vietnamese, Kenyan, or Puerto Ricans), for example, shared world views, values, and beliefs.

The VIP uses the virtual world, Second Life (SL), an online program that allows users to develop relatively realistic avatars—of diverse gender and racial backgrounds—and interact with other live participants around the world. The program is free and relatively easy for students to download on their personal computers (students also had the option of using computers owned by the university). In this class project, students selected one of the avatars below (see Fig. 17.1) that was likely to have a different racialized experience from his or her own, but of a gender experience which is more consistent with their own (students identifying equally with both male and female genders may choose either). Students were then required to spend a total of 2 h in the virtual world visiting various diverse social environments (predetermined by the instructor) and kept a log and reflection journal about their experiences. While virtual worlds are increasingly being used in educational contexts (e.g., Hew and Cheung 2010) to the author's knowledge, this is the first exercise described in the literature that uses virtual world technology to encourage empathic understanding across social identities and statuses.


**Fig. 17.1** The Avatars (**a**) Nyque, (**b**) Keitichandesu, (**c**) Blue Moon Odom, (**d**) Zufan

## 17.2 Previous Uses of Virtual Worlds in Educational Settings

Increasingly, virtual world technology is being used in the classroom. Minimally, educators are recognizing its potential for supplementing traditional teaching modalities. More idealistically, some educators recognize this technology as a means of offering students novel, one-of-a-kind interactive experiences with the potential for challenging students’ modernist assumptions and fostering constructivist approaches to learning (Barab et al. 2001; Dickey 2011; Hew and Cheung 2010; Lu 2008).

In a comprehensive literature review, Hew and Cheung (2010) identified three primary ways in which virtual world technology has been used in the classroom. The first approach has been as a means of communication, for example, as a tool for hosting remote group discussions among students (Hew and Cheung 2010) or in at least one case, to facilitate language learning among English-language learners (Peterson 2006). The second approach has been to capitalize on the 3D visual platform to facilitate spatial learning; this has included providing international students with a remote spatial orientation to campus environments

(Praslova-Førland 2008), environments for which students can explore visual art and have related discussion (Lu 2008) and environments for Social Work students to explore the effects of discrimination such as a visit to a virtual Holocaust museum (Reinsmith-Jones et al. 2015). The final approach has been to provide students with action-based experiential exercises, for example, providing teachers-in-training with live classroom environments in which they are required to develop and facilitate classroom exercises (Quintana and Fernández 2015) and immersive medical training settings for healthcare professionals (Wiecha et al. 2010).

Although novel uses for virtual worlds in educational settings have begun to proliferate, empirical evaluation of learning outcomes related to virtual world use has been limited thus far. The majority of studies that have evaluated learning outcomes have been quantitative, descriptive approaches to research (Hew and Cheung 2010). For example, in the study with Social Work students described above, 70% of the students ($N = 60$) somewhat or very much agreed that the virtual visit to the Holocaust museum was a good way to learn about the effects of oppression (Reinsmith-Jones et al. 2015). In one experimental approach, Spanish-language learners in the Netherlands ($N = 36$), randomly assigned to either a videoconferencing or virtual world (SL) condition in which they participated remotely in language learning tasks with native language speakers, had significantly better growth in Spanish oral communication than control group students who completed the same tasks with nonnative speakers in the classroom (Canto et al. 2013).

In addition to evaluation of specific exercises, a recent study examined students' overall experiences with virtual learning environments. Participants ($N = 116$) recruited from various learning environments within SL reported a variety of gratifications with the virtual learning experiences, including convenience and entertainment and having shared experiences, and these gratifications were associated with students' motivation to continue learning through virtual environments (Gallego et al. 2016). In contrast to student users' mostly positive experiences with virtual learning, educators remain hesitant to adopt virtual learning in the curricula. In one study among educators ($N = 223$), 44% felt their universities did not have adequate technology, 29% felt a lack of teaching support, and 29% felt they did not have the time for engaging in virtual learning (Gregory et al. 2015). Certainly, adoption of virtual learning exercises may appear daunting to novice users. Thus, one goal of this paper is to provide teachers who may be interested in using virtual worlds with a cost- and time-effective and user-friendly protocol for conducting the VIP or a similar exercise. Our primary goal, however, is to qualitatively evaluate students' experiences with the VIP. Consistent with qualitative epistemology, our approach to this analysis is inductive; students' descriptions of their experiences and learning processes with the VIP are organized thematically as they emerge rather than seeking confirmation or rejection of predetermined hypotheses (Creswell 1998). In the next section, we describe the VIP including the reflection assignment on which this analysis is based.

## 17.3 The VIP

Students were required to participate in the VIP as part of an experiential learning component of their Cross-Cultural Psychology class. The goal for this project was to give students insight into the subjective racial experiences of people of color. Students were allowed to either download SL on their personal computers or schedule a time to use a computer and the SL program, provided by the instructor. In a class of 16 students, all students but one opted to download the program. The program is free and is available for both Mac and PC download at www.secondlife.com. An in-class tutorial covering the basic functions of SL including walking, chatting, and private messaging was provided.

Avatars of various racial backgrounds (i.e., Asian, Black, and White) were created by participants in a previous study on racial interactions conducted by the author of this paper and were lent to students for use during their VIP experience. This original study included monoracially identified Black, Asian, and White participants who were required to develop self-resembling avatars. Four avatar accounts were no longer in use by participants and were adopted by the author, with former participant consent, for the purpose of the VIP (see Fig. 17.1). This approach to avatar development ensured that the avatars being used by students in this project were not simply stereotypical characterizations of racial group members, but rather nuanced representations of real people and their racial appearances.

To assign avatars, students were asked to email the instructor stating how they identified racially and if they had a preference for which avatar to use, as long as the avatar’s race was different from their own. Students were encouraged to use an avatar of the same gender, but different race, in order to focus their experiences for this project on racial experiences. Because there were only four avatars of color available for use, and 13 of the 16 students in the class were White, some students shared avatars and were required to coordinate times in which they would use the avatars so they would not overlap.

For the assignment, students were required to log into their user account and spend a total of 2 h interacting with other avatars online. They were told that this time could be broken up into increments, although it was recommended that such increments were no shorter than 30-min sessions, to ensure a relatively sustained immersion. Participants could engage in any activity they wanted but were required to visit three locations within SL. The instructor previously selected these locations because they had relatively high user traffic (thus ensuring social interactions) and because each location had a relatively different level of diversity: (1) The Blarney Stone is a pub adorned with Irish-themed décor and is most often populated with White-appearing patrons; (2) Hollywood Airport is a popular hang-out location where users can mingle and take local plane rides and is often populated with racially diverse appearing avatars; (3) Soul Vibrations is an outdoor lounge and dance club and is most often populated with Black (African American and Caribbean)-appearing avatars.

During their 2 h in the virtual world, students were asked to keep a written log of their experiences. It was recommended that students complete a log entry every 10–15 mins or so while online. Students were encouraged at this point to focus on the content and detail of their social interaction and not yet on their thought processes during the interactions. The following week, students were required to turn in reflection papers in which they then spent some time thinking about the meaning of their experiences and what they had learned. This paper describes a thematic content analysis of students' reflection papers. In particular, the author was interested in understanding the students' processes and content related to learning about the racial experiences of people of color.

## 17.4 Method

The VIP was evaluated by analyzing students' reflection papers. The author's analytic approach followed a phenomenology, a method aimed toward generating rich description of multiple people's lived experiences of a phenomenon. The data collected were well suited for a phenomenological analysis given that approximately 10–15 participants are recommended for this approach and because the focus of the analysis was on describing, in-depth, the multiple possible ways in which participants experienced the VIP. As with qualitative research in general, this approach to data analysis was inductive, allowing themes to emerge from the data, rather than a deductive approach in which a priori hypotheses are developed and then confirmed or disconfirmed by the data. The methodology does not aim to address the generalizability of the experiences discussed, but rather to offer qualitative rich descriptive detail about experiences of the participants involved in the study. Thus, the thematic findings presented here should encompass a range of possible experiences but may or may not reflect the modal experience of college students who participate in the VIP in the future.

### *17.4.1 Participants*

Participants included the 16 students (ten females, six males) who were enrolled in the researcher's Cross-Cultural Psychology class. The university setting is a predominantly White, liberal arts college in the Northeast. The majority of the students were self-identified as White, with the exception of one Caribbean-born immigrant female who self-identified racially as Black and a Japanese male international student who self-identified racially as Asian. One White male was a European international student, and one White female was an international student from Central America. Avatars were distributed to students as follows: six females operated Nyque, four females operated Keitichandesu, four males operated Zufan, and two males operated Blue Moon Odom (see Fig. 17.1). All participants completed the VIP and reflection papers as part of their course requirement. Consent for the researcher to use their reflection papers in the current analysis was sought after completion of the course and after grade submission so that students would not feel coerced to allow their papers to be used. All 16 students agreed to have their papers used in the current analysis.

### *17.4.2 Data Analysis*

In the data analysis stage, the researcher and a colleague (see section on Verification below for more detail on the role of the colleague) reread each student paper and extracted all "significant statements" (sentences or paragraphs) from each paper. In a phenomenology, this process is sometimes referred to as "horizontalization of the data" as each statement is seen as having equal worth (one statement is not seen as being more valuable or more "true" than another) and is laid out for examination and thematic clustering (Moustakas 1994). For ease of analysis, each statement was assigned an "open code" or a descriptive label. Examples of codes at this stage included "friend request rejected by White peer," "ignored by group of White avatars," and "realized need to be hyperaware." In the next stage of phenomenological analysis, the researchers then collapsed codes within broader categories, which then comprised the themes presented in the results and discussion section of this paper. For example, the first two open codes described above were collapsed into the broader theme of "Experiences of White racism." The third open code was collapsed into the theme of "Insight into double consciousness." Once working themes are established, it is recommended that the research write both "textural descriptions" (what specifically was experienced by participants) and "structural descriptions" (how the phenomenon was experienced by the participants with attention to specific contexts) related to each theme. These descriptions formed the basis for the introductory paragraph and description within each theme that are presented in the results section below. In a final stage, the author returned to the "open codes" and selected quotes that best illustrated each of the themes.

### *17.4.3 Reflexivity and Verification*

Qualitative research guidelines for *reflexivity* and *verification* (Creswell 1998; Fassinger 2005) seek to ensure sound and trustworthy research. Reflexivity is an explicit examination of the ways in which a researcher's personal experiences and statuses might interact with data analyses. Phenomenology specifically asks the researcher to write about his or her own experience with the phenomenon under investigation in order for the researcher to develop an awareness of possible assumptions and expectations, which may influence their interpretation of participants' stories. Once the researcher has become aware of his or her personal experiences, he or she is in a better position to set aside or “bracket” assumptions to minimize researcher bias in the analysis. For example, in the researcher’s journaling about his own early experiences in SL as he was getting familiar with the program, he wrote about an experience where he was invited by another avatar to join a vampire community. After accepting the invitation, he was teleported to an island where he was joined by a group of three vampires who brought him to meet the “vampire king.” Upon meeting the king, the king made fun of the researcher’s shoes, which were to the rest of the group an apparent indication of the researcher’s newness and novice status in SL. The researcher described how surprised he was at how suddenly uncomfortable, anxious, and belittled he felt in real life, despite being aware that he was interacting through an anonymous avatar on a computer. He also described how the affective experience reminded him—or perhaps even evoked—feelings of marginalization he experienced as an Asian American, particularly in his youth. Being aware of the capacity for social interactions in SL to evoke emotional responses allowed the researcher to be sensitive to participants’ affective descriptions of their experiences. Simultaneously, the researcher became aware of the need to not assume that other participants’ experienced interactions in SL affectively.

In addition to reflexive processes, it is also recommended that researchers engage in a *verification* process to ensure that their analyses are representative of participants’ stories (Fassinger 2005). During the data analysis stage, the author sought verification with a colleague, Dr. Maryam Jernigan, who herself has extensive experience with qualitative research and is knowledgeable about topics covered in this paper such as racial identity and transformative educational approaches to teaching and education. During this process, the researcher and Dr. Jernigan independently conducted analyses and then met to discuss overlapping themes and to discuss and resolve any differences in the way participants’ stories were interpreted. In general, both the researcher and Dr. Jernigan independently reached similar descriptions of participants’ experiences with the VIP with some minor differences in perception. For example, while both the author and Dr. Jernigan recognized some White participants’ resistance to seeing negative interactions with other White avatars as racism (see results below for greater description of this theme), Dr. Jernigan interpreted these experiences as more of a normative process of White racial identity development rather than a static rejection of the assignment.

## 17.5 White Students’ Experiences with the VIP

A total of six themes emerged from students’ reflections on their experiences with the VIP. In this section, each theme is presented along with supporting quotes (in their original form, including spelling and grammar errors) as well as some discussion points related to each theme.

### *17.5.1 Experiences of White Racism*

Some students described being targets of racism. Being ignored or excluded by other avatars was a relatively common experience for students while piloting non-White avatars. Some students, particularly White students, contrasted their experiences of racism while piloting a non-White avatar with their experiences as a White person in real life. Rebecca, a White female student from the USA, piloting Nyque (Black female avatar) described being at the Blarney Stone and noticing how White avatars seemed to be less interested in talking to her than other non-White avatars:

> Not only was I not a familiar face at Blarney Stone, I was an unfamiliar black face. The majority of the people there were light skinned [White], and completely involved in the conversation they were having. I understand that it might be typical of users of SecondLife to already have a "norm" of conversation and a particular group of people that they always talk to, so I wasn't completely surprised at [the] lack of welcome. Still, the only person involved in the conversation already going on that made an effort to talk to me was an avatar that also had dark skin. I had been in the virtual world for all of 20 minutes and I was already being "left out," and it appeared to be pointedly so by a group of light skinned avatars. ∼Rebecca

Aurora, a White female student from the USA, piloting Keitichandesu (Asian female avatar) also speculated that she would have had more interactions at the Blarney Stone Pub if she had been White:

> If I were to have been piloting an avatar that was the same race as myself, [C]aucasian, then I guess some things would have been different. I wonder if more people would have chatted with me or if more people would have responded to my chats because of my race. ∼Aurora

Logan, a White male student from the USA, piloting Blue Moon Odom (Black male avatar) also had a similar experience and compared his experience as a Black male avatar with his experience as a White male in real life:

> Out of the three white people I tried to talk to none of them answered. I do think the way I looked affected this, because they all walked away when I messaged them individually. Without getting to know [who] I truly was, my looks alone were enough to deter them away. This was an unusual feeling for me because I don't think anyone in my lifetime has looked at me and walked away because of the way I look. It was a little frustrating and made me want to tell the people that my looks have nothing to do with who I am as a person. ∼Logan

Models of contemporary racism suggest that explicit racism, such as obvious exclusion of people based on skin color, is an "old-fashioned" form of racism that is less prevalent today, compared to more implicit forms of racism (Bonilla-Silva 2003; Neville et al. 2000; McConahay 1986). Yet, the students' stories suggest that explicit racism is relatively persistent in the virtual world. One perspective is that people are more willing to expose their explicit racism in online settings because of an "online disinhibition" effect and anonymity (Suler 2004; Tynes et al. 2013).

### 17.5.2 Experiences of Interminority Prejudice

White (or presumably White) avatars in SL were not always the culprits of differential treatment. In some cases, non-White avatars were victims of explicit prejudice[1] from other minorities. Some of the prejudice experienced between minorities was at times even more explicit than White racism. Mandy a Central American international student, who identified as White, and who piloted Nyque (Black female avatar) described an incident with another Black female avatar while at Hollywood Airport:

> While I was walking around and exploring the area after going on my plane ride, I came across what I later gathered to be a couple. These two avatars were black, one male and one female. I walked up to them and stood next to the male avatar, I had not even said "hello" yet when my message box prompted to what was extremely eye opening for me. The black woman that was standing next to the black male messaged me and said "move you black b****," ironically, she was black too. This incident really did it for me, as here is where I concluded that racism is indeed real and present even in something as simple as a virtual world. The fact that my avatar was called a "black b****" by another black woman made me wonder how people can be so fooled by the concept of race in regards to status. ∼Mandy

Hayato, a Japanese male international student piloting Zufan (Black male avatar), visited a location in SL that resembled Japan. He spoke with an Asian-appearing female avatar in Japanese but was surprised to find that she was very preoccupied with his racial appearance despite speaking Japanese:

> Another reason [that he believed her to be preoccupied by his race] was the fact that she said "oh u r black. . . ." She might not say "oh u r black" when she meets a black person in the real world. Furthermore, she would not have to mention people's race. Ultimately, I could not figure out the reason why she mentioned about my avatar's race, but at least for her, my avatar's black skin was something to pay attention to. ∼Hayato

For some White students, experiencing interminority prejudice was awakening in that they had not realized that people of color also have tensions within and between their communities. Aurora, piloting Keitichandesu (Asian female avatar), seemed to expect that she would be more welcomed in the primarily Black Soul Vibrations location compared to the predominantly White Blarney Stone:

> It was very exciting to see a lot more racial diversity in Soul Vibrations. I was hopeful for more responsive conversations with people. I was very curious if people would try and start a conversation with me, so I just hung out for a couple minutes, walking around a bit and checking the place out. When no one did, initiating a conversation with an African American woman named Diamondp, I was hoping for a decent conversation. It was very disappointing when she did not respond to my greeting. Perhaps this was due to the fact that I was of a different race than her. ∼Aurora

[1] We reserve the use of the word "racism" for discriminatory interactions perpetrated by Whites against people of color. The term "prejudice" is used when describing discriminatory interactions perpetrated by people of color against other people of color. Racism can only be perpetrated by a group that is in a position of sociopolitical power, such as Whites (Pinderhughes, 1989).

Jim, a White male student from the USA piloting Blue Mood Odom (Black male avatar), describes an incident where he was approached by a Spanish-speaking avatar; Jim believed that the other apparently Latino avatar approached him because he thought he was also Latino, but left the conversation when he realized that James did not speak Spanish:

> I did feel quite uncomfortable with the encounter. It was also quite interesting to me that I was rejected by a non-white (ethnic minority). I understand a majority feeling of alienation amongst ethnic minorities, but I failed to realize the possibility and significance of inter-minority prejudice. ~Jim

With the rapidly increasingly multiracial context in the USA, it is increasingly important for students of race and diversity courses to move "beyond Black and White" (Alcoff 2003; Tawa et al. 2013) and to recognize that the experience of a racial minority group member (e.g., Black) is not only characterized by the nature of his or her relationship with the White majority group, but also their unique relations with each ethnic minority group (e.g., Asian, Latino).

### *17.5.3 Experiences of Racial Microaggressions*

Microaggressions include slights or differential treatment of people based on racialized assumptions (Sue et al. 2007a, b). For example, students piloting Black avatars experienced having others assume they were poor, and students piloting Asian avatars experienced others perceiving them to be "perpetual foreigners" (Sue et al. 2007b). Clément, a White European international student from France, piloting Zufan (Black male avatar) provided a sample from a chat log depicting an experience where he was assumed to be poor, perhaps because of his racially Black appearance:

> Here I can tell about a noticeable fact that happened to me. When I first introduced my self to the American girl, she answered this way:
>
> [2013/10/26 11:49] zufan: hi
> [2013/10/26 11:49] Dee Canucci: hello
> [2013/10/26 11:49] zufan: I am new in second life :)
> [2013/10/26 11:49] zufan: do you have any advice ?
> [2013/10/26 11:50] zufan: what is fun to do
> [2013/10/26 11:50] Dee Canucci: so I suppose you need money?
> [2013/10/26 11:50] zufan: mhh, I do not know
> [2013/10/26 11:50] zufan: Should i need money ?
> [2013/10/26 11:50] Dee Canucci: nah
> [2013/10/26 11:50] Dee Canucci: sorry...I thought you were going to beg

Clément reflects on this interaction:

> I did not notice it at first, but after reading the conversation again, I thought: Did she ask me about the money because I was new in the game, or because my avatar is black? ~Clément

Both Aurora and Marcia, a White female student from the USA, also piloting Keitichandesu (Asian female avatar), described social interactions where other avatars appeared to be preoccupied with finding out where they were from, a common microaggressive experience for Asian Americans (Sue et al. 2007b). Aurora suggests that the male she interacted with also may have been exotifying/sexualizing her, also a common micoraggressive experience, particularly for Asian-American women (Sue et al. 2007b):

> Someone named Hussein came over and talked to me, asking me where I was from and what I do, I returned the questions and he is a software consultant from Dubai. He made it clear that he had other intentions beyond becoming friends in the game. ∼Aurora

Marcia describes two experiences where other male avatars seem preoccupied with finding out where she is from. While Marcia reported that these experiences made her uncomfortable, she was tentative about whether or not race contributed to these interactions:

> After telling him that I was from the United States he never answered and walked away. I wondered if he stopped answering because of where I said I was from. It made the situation awkward, even though it wasn't in person and only over the computer. It felt uncomfortable because, even though I didn't know this person, they just stopped responding and I wasn't given a reason why . . . . ∼Marcia

She continues by describing another possibly microaggressive experience, this time from a Black male:

> Another uncomfortable experience that I had was with an avatar named "THE DUDE." His avatar was of black skin. He was asking very personal questions about my life and was trying to get my to tell him where I lived but he wouldn't answer any questions about himself. It was kind of creepy so I stopped talking to him. This was very uncomfortable to me because I didn't know who they were and I was not okay with telling someone that I didn't know personal things about myself on the internet. ∼Marcia

Despite feeling uncomfortable, Marcia is tentative about considering such experiences as "racism":

> I didn't experience any racism towards myself or between others. Everyone seemed to be friendly towards one another and accepting no matter what your racial background was. The only possible racist experience I had was with the man that stopped talking to me and walked away once I told him that I was from America. But, I can't be sure as to why he stopped talking to me. ∼Marcia

Jim, piloting Blue Mood Odom (Black male avatar), describes an experience where a group of White avatars are very inviting toward him to join their conversation; yet, he suspects they are being overly nice to him because they feel uncomfortable in his presence as a Black male:

> Despite the one negative experience others were inviting. They may have truly been nice people hoping to converse with a new acquaintance, although part of me felt like they were almost overcompensating in order to satisfy their inner guilt encompassing their feelings of being around someone different. ∼Jim

Because of the subtle nature of racial microaggressions, students did not always immediately perceive these experiences as racism. Students piloting Asian avatars, in particular, seemed tentative in their analysis of such experiences as "racism," which may reflect the complex way in which Asians are racialized in the USA. Asians in the USA, for example, are frequently racialized as "perpetual foreigners" and as outsiders in the US context (Sue et al. 2007b). Many Asians in the USA report that others tend to have a preoccupation with where they are "from"; the underlying message in these interactions is that one is never really from the USA. This type of nuanced racialization may be particularly difficult for students to detect, particularly when they are only midway through the semester, because it is not consistent with their expectations about what racism might look or feel like.

### *17.5.4 Insight into Double Consciousness*

Students were surprised to realize that the psychological experience of people of color was not only characterized by experiences of racism but also by the constant need to be aware of the *possibility* of racism and the constant ambiguity around whether or not their racial appearance influenced other people's actions and behaviors. People of color in the USA experience what W.E.B. DuBois (1903) referred to as a "double consciousness"; by necessity people of color must not only be aware of their own feelings and thoughts but also how White people are perceiving them, what White people assume their motives are, and how their behavior is interpreted by White people. Colleen, a US-born White female student, also piloting Nyque (Black female avatar) was surprised to realize that her racial appearances affected her own expectations about others' perceptions of her and her resulting behavior:

> . . . it was my prejudgment that took what actually happened by surprise. I expected people to be hesitant of me or only people of the same race [Black] to come to me . . . .I think it plays a big part in who we contact. ∼Colleen

Other students who, like Colleen, reflected on their surprise about how their racial appearance affected their own thought processes, related this experience to their experiences of being White in real life. Logan (piloting Blue Mood Odom, Black male avatar) and Jennifer, a White female student from the USA piloting Keitichandesu (Asian female avatar), shared the following:

> While playing, I found myself wondering a lot about what other people thought of me whenever I walked into a new place. I never usually think this way in real life. I'm unsure if I thought about it so much because I was conscious of the assignment, or if it was because I was black in a mostly white environment. I consider myself to be very open minded and accepting of other races and beliefs, but this was the first time I had ever actually considered how different it was to be a different race. If I spent a bunch of time thinking and worrying about what other people thought and expected of me in a video game with just an avatar, what must it be like to have those feelings exaggerated in real life? ∼Logan

> Reflecting upon my experiences in Second Life I find I am unclear about a few things. Whether I acted differently because I knew I was not the race I am accustomed to, or if people treated me differently because I was of a different race. Perhaps I did interact more

> timidly with people because I was not sure how to act or how people would react to me. I had never really considered my own experiences as a Caucasian person before, but now I can recognize it as part of my identity. I interact with people based not only on my personality, but because of my learned ethnicity as well. ∼Jennifer

Students also reflected on the psychological discomfort they experienced due to the possibility of being seen by others as fulfilling negative racial stereotypes. Clément, piloting Zufan (Black male avatar), described a scenario where he was at a predominantly White bar (Blarney Stone) and a virtual music band was playing. While a number of people were tipping the band (in SL this involves transferring "Linden dollars" or SL currency to another users account), Clément did not since he was borrowing the account and there was no money on the account. It occurred to him that people might have attributed his failure to tip to his racial appearance:

> I am so impressed when I arrived in something that looks like an actual concert. I stay around 20min inside and decide to leave, as I figure that most of the people are donating! (Thus, they pay for the virtual concert). In this part, the only comment that I can make is that I felt kind of bad when I figured that many people were paying and that I did not! So when I left after 20 min without saying much, I had this feeling of being like a thief, and I caught myself thinking: "The stereotype of the black guy that takes advantage of people without rewarding them." In this situation, I think that if I would have been white I would not have had the same impression, or at least not in the same way. It was very interesting for me to notice this element. ∼ Clément

For some White students, piloting an avatar of color gave them insight into the experience of "double consciousness" described by DuBois (1903). Students realized that the ambiguity and the "not knowing" consumed much of their psychological resources, and that this, in itself, was part of the experience of being a person of color. These experiences facilitated students' learning about complex concepts related to race. For example, Clément's experience and realization helped him understand—both intellectually and affectively—the concept of "stereotype threat," discussed later in the semester. According to stereotype threat theory, people of color's performance on tasks are often inhibited by anxiety related to being seen by others as fulfilling negative stereotypes; for example, in a classic study, Black students informed that they were taking a test that was "diagnostic of intelligence" were significantly outperformed by Black students taking the same test but told that it was "nondiagnostic of ability" (Steele and Aronson 1995).

### *17.5.5 Influences of Racial Contexts on Racial Experiences*

As described earlier, students participating in the VIP were required to visit three predetermined locations in SL, each of which had considerably different degrees of apparent diversity. Some students realized that the way they were received and treated by others—and therefore how they felt—depended on the setting they were in. Mandy and Rebecca piloting Nyque (Black female avatar) and Logan piloting

Blue Moon Odom (Black male avatar) described feeling more welcome in more racially diverse settings when compared to primarily White settings:

> The second place I visited which was also one that was recommended was Soul Vibrations. Here was where I got the most interactions but ironically, I noted that all the avatars were also racially black. As I landed from flying to my destination people began to blow up my message box, they were very welcoming. An avatar even asked me to dance, which was done so by another black woman. Here in, Soul Vibrations was where I felt the most welcomed. I felt very relaxed and lighthearted. I do think it was because everyone around me was of the same color as my avatar and so they were all very open to having a conversation with me. I believe that in this particular instance people were more welcoming to me because they too were also racially black, unlike in the Blarney Stone Irish Pub, where it was difficult to even get a response. ~Mandy

> I already couldn't help but start to speculate on the drastic change that I experienced in Soul Vibrations versus Blarney Stone when I wrote my initial journal entry. I went from struggling to find anyone that actually wanted to talk to me, to trying to figure out who it was that was messaging me because so many messages were addressed to me at once. At the most obvious level, the biggest difference between the avatars at Blarney Stone and the ones at Soul Vibrations were that at Soul Vibrations they were generally much darker in skin color, and much more curious to get to know who I was. ~Rebecca

> The Hub consisted of approximately ten occupants, but the experiential feel was quite different than my initial. I was welcomed by a woman who seemed rather intrigued by my presence. Her inviting tone was exemplified by her offering of virtual gifts. Perhaps a cynical view, I believe I received more attention at my second location because nine out of ten occupants were seemingly ethnic minorities. ~Logan

Some students, particularly White students, further reflected on how their experiences of shifting contexts as an avatar of color was different from their experience in real life as a White person. Rebecca reflected on how this experience in the VIP affected her understanding of her own White privilege:

> The virtual immersion project opened my eyes to how my identity as a white female may make it easier for me to enter into new situations and be accepted in multiple social contexts, versus how if I were a black female, the way I was socially welcomed into new environments may not be as warm. After having had the experience of being Nyque in SecondLife, I've now begun to think about the ease in which I transfer in and out of different places and groups of people, and how if I were of a different race, the ease might just not come so "easy." ~Rebecca

In this author's experience teaching courses about race and culture, students can relatively easily learn intellectual arguments for understanding that race is a biologically meaningless concept. What is often more difficult for students to understand is that race, despite being biologically meaningless, remains a socially significant concept (Marks 1996; Omi and Winant 1994). Students' experiences of "feeling different" in different social settings facilitated their ability to fully grasp the idea that race is a "social construct." This was particularly the case among White students, many of whom did not have life experiences which required them to negotiate multiple racial contexts in their day-to-day lives.

### *17.5.6 Resistance to Seeing Race*

Instructors of diversity courses are aware that teaching about racism and oppression is often met with resistance, particularly among students that hold positions of privilege. In fact, within a transformative education pedagogy, resistance is not only expected, it is conceptualized as a mechanism through which true learning about racism and oppression can occur (Helms 1990; Suyemoto et al. 2009). Thus, it was not surprising that some students rejected the notion that race affected their interactions in the VIP. Students' resistance to seeing the role of race took various forms including feeling the virtual environment was unrealistic, forgetting they were being seen by others as racial minorities, and attributing differential treatment to factors other than race (e.g., being a "newbie" in the virtual world).

Some students described the virtual environment and the experience of piloting a person of a different racial background as being too unrealistic and foreign to them and thus difficult to provide conclusive evidence for the role of race in social interactions. Percy, a White male from the USA, piloting Zufan (Black male avatar) described his difficulty with drawing conclusions about the role of race based on his experience in the VIP:

> While my interactions were truly interesting with other Second Life users, I find it hard to use any of my experiences to apply to race-based theories. I thought I would surely experience aversive racism through interacting with people as a black male avatar. I felt almost mistaken to assume this though. It seems that a program such as Second Life cannot provide any substantial data to be used in researching racial interactions. I didn't feel as though I was in the body of a black person. I kept forgetting that I was seeing through the eyes of a black avatar. I wonder if I would have experienced this differently as a white avatar. The interactions that happened in Second Life felt alien to me regardless of race, as I would never interact with strangers through a computer anyway. ∼Percy

However, Percy continues by describing a differential pattern of interaction with Black and White avatars, suggesting that race did in fact play a role in his interactions:

> I thought that a valid conclusion that could be made was the black avatars felt comfortable messaging me because I was also a black avatar. I did not feel uncomfortable around white avatars though. Of the four major interactions I had with other avatars, two were white and two were black. Neither of these conversations I started myself. When examining aspects of aversive racism, I never once felt as though I was a victim of it. I think many people did not speak to me because I was new to the bar or club and these users already [knew] each other. ∼Percy

Connie, a White female student from the USA, piloting Nyque (Black female avatar) did report feeling awkward, but attributed this awkwardness to general discomfort that is felt in any new social situation (not just a cross-racial social situation):

> I think overall [that] race didn't affect anything to be honest. I had completely forgotten I was even a different race because I was so focused on the project and interacting with

> people and seeing how they interact with me and relating it to real life. The only female who made contact with me wasn't nice and no other female contacted me after that. They already seemed to have their group of friends and social events and I felt awkward and intrusive coming in on the chat, which is relevant in real life as well. ∼Connie

A number of students, like Percy, suggested that some of the differential treatment they received in SL was due to the "newbie" appearance of their avatar. It appears that some more prolific SL users may have some prejudice toward novice users, and this prejudice may account for some students' overall feelings of being ignored. However, "newbie" prejudice would not explain differential treatment by racial in-group and out-group members. Connor, a White male from the USA piloting Blue Mood Odom (Black male avatar), also questions if his newness was the primary cause of his being ignored:

> I identify as a white male, and the avatar that I used was a black male. He looked like an average black male, but with a lighter skin tone. He was dressed casually, nothing too crazy. This may have actually been a problem though, since my only interaction with anyone else revealed that most Second Life players don't tend to talk to newbies, which is what I looked like. It probably didn't help that I had some issues with understanding all the controls and spent a lot of time walking in circles and sitting on bars. I tried talking in the group chats with the people around me, but was ignored completely. ∼Connor

The goal of the VIP was not to objectively determine if students did or did not experience racism, but rather to provide students with the subjective experience of someone from a different racial background than one's self. Multiple stories of differential treatment, particularly by non-White avatars, do seem to suggest that racism was prevalent in SL. This does not exclude the possibility that other types of non-racial prejudice were present as well, such as "newbie"-related prejudice. Pedagogically what is of particular interest was the ways in which students engaged with the project. Students resisting perceiving racism also frequently reported "forgetting they were being seen as a racial minority"; in other words, some students may have disengaged with the subjective-perspective taking component of this exercise. Color-blind attitudes (Neville et al. 2000) and self-professed obliviousness to seeing race are common information processing strategies among White people in a "contact" stage of White identity development (Helms 1990). Nonetheless, students' ability to eventually work through their resistance to seeing racism in the VIP may have ultimately contributed to even fuller learning about racism and oppression. Percy, in a final reflection at the end of the semester, explicitly described how he realized that the way he approached the VIP project was the same way he tended to respond to his Black friends when they talked about experiencing racism; instead of seeing the experience through "their eyes," he often sought evidence to support their claims or considered alternative explanations for why they were treated differently. Although he met his experience in the VIP with resistance, over time this experience contributed to his learning about his own tendency to invalidate the perspective of his peers of color and his related racial privilege.

## 17.6 Conclusion

As a relatively recent phenomenon, the use of virtual world technology in the classroom brings about new pedagogical and ethical challenges, but simultaneously has great potential for providing students with innovative interactive learning experiences. This paper is a preliminary analysis of students' reflection papers based on their experiences with one specific project, the VIP. Educators are invited to borrow the rubric of the VIP for adoption in their own classes,[2] and the analysis in this paper should offer educators' some expected outcomes and challenges. In addition, although further empirical investigation is needed to support the effectiveness of virtual worlds as a tool for fostering students' subjective understandings of people's experiences across social identities, this analysis may provide future researchers with some specific areas of inquiry. For example, as a follow-up study to this project, the first author is currently investigating the extent to which participants experience physiological distress (i.e., detected using a galvanic skin response and heart rate variability machines) while piloting same and different race avatars. Such findings could help establish the degree to which interactions within virtual worlds operate as analogues of interactions in real life. This research is designed to address some students' concerns about the real-life transferability of the virtual context.

Additional challenges and potential future directions for researchers have been identified in the literature. Wang (2011), like some of the VIP students, is particularly concerned about the "instability of identity" behind the avatars. For example, students in the VIP were more accurately interacting with other people's "second lives" which may or may not reflect their "first" or real life. Moreover, students' motivations for interaction in the virtual world may be discrepant from other online users' motivations, which are more likely to be for the purpose of social networking or for business. Both Wang (2011) and Childs et al. (2012) raise concerns about students' exposure to "griefing," adult content, or being targets of inappropriate behavior by others. Despite these important pedagogical and ethical concerns, virtual worlds also have the potential for not just supplementing traditional course content but also facilitating a shift to more constructivist or transformative education models of learning in which the student becomes an active participant in the construction of knowledge (Barab et al. 2001; Dickey 2011; Hew and Cheung 2010; Lu 2008).

Suyemoto et al. (2009) describe five pedagogical goals of transformative education. The first is to foster a student's ability for *perspective taking*; in the VIP, students quite literally are asked to "walk a mile" in someone else's shoes, encouraging the development of the complex subjective experiences of people with different social identities and experiences. The second goal is to *problematize*

[2]The avatars used in this project are also potentially available for educators to "borrow" for their own students' use for completion of the VIP or related projects. Interested educators should send a brief proposal of their planned use of the avatars to the author. Requests will be considered on an individual basis.

*complex social variables*; students learn through the VIP—both intellectually and affectively—that race is a highly complex construct. For example, students learn that people are treated differently simply because of how they are perceived or categorized racially by others and that specific differences are privileged in some social contexts but not others. The third goal is to encourage students to *attend to power differentials*: students learn in the VIP that being perceived as a member of a racial minority group member is a considerably more challenging social experience than being perceived as White. A fourth goal of transformative education is to encourage student's *personalization of knowledge*; rather than simply being told by an expert that Black people experience racism, students in the VIP experience racism personally and reflect on how these experiences shape their understandings of racism. Finally, most broadly and perhaps most ambitiously, transformative education models seek to shift students' *epistemological inquiries*; students are encouraged to not only develop a critical analysis of the subjects taught within a specific class room but also an ability to develop their own line of critical inquiry that can then be applied to all of their learning experiences. The VIP project provides students with access to one such tool for complex social learning and experimentation.

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# Chapter 18
# Question-Answering Virtual Humans Based on Pre-recorded Testimonies for Holocaust Education

**Minhua Ma, Sarah Coward, and Chris Walker**

**Abstract** In this chapter, we present Interact—a project which builds question-answering virtual humans based on pre-recorded video testimonies for Holocaust education. It was created to preserve the powerful and engaging experience of listening to, and interacting with, Holocaust survivors, allowing future generations of audience access to their unique stories. Interact demonstrates how advanced filming techniques, 3D graphics and natural language processing can be integrated and applied to specially recorded testimonies to enable users to ask questions and receive answers from virtualised individuals. This provides a new and rich interactive narrative of remembrance to engage with primary testimony. We briefly reviewed the literature of conversational natural language interfaces; discussed the design and development of *Interact*, including how we mapped the current proceedings of testimony and question-answering session to human-computer interaction and how we generated/predicted questions for each survivor using a lifeline chart; the 3D data capture process, generating 3D human; and natural language processing; and argued that this new form of mixed reality is a promising media to overcome the uncanny valley. Subjective and objective evaluation is also reported. The chapter is a longer version of a short paper presented at the ACM OzCHI conference (Ma et al., Interact: a mixed reality virtual survivor for holocaust testimonies. In: The proceedings of 27th annual meeting of the Australian Special Interest Group for Computer Human Interaction (OzCHI '15). ACM, New York, pp 250–254, 2015).

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**Keywords** Mixed reality • Virtual human • Natural language processing • Question-answering • Holocaust survivor • Pre-recorded video testimony

## 18.1 Introduction

A key part of Holocaust education is listening to and interacting with a Holocaust survivor. In some museums and education centres, such as the National Holocaust Centre and Museum in the UK (NHC), Holocaust survivors speak to the audience, sharing their story and answering questions about their experience. Listening to and meeting a Holocaust survivor in person provides an opportunity for people to attend to a person's full story, from which they can gain deeper insights, rather than listening to *snippets*. This builds empathy between the audience and the survivor, as the audience develop their knowledge and understanding of the Holocaust and genocide.

Listening to a Holocaust survivor's personal experience and interacting with them are a key part of Holocaust education. However, soon this experience will be lost. There are few Holocaust survivors remaining in the UK who are able and willing to share their story publically in person. Each year survivors pass away or become too frail to deliver their testimony in person. There is an urgent need to capture their experiences.

Previous Holocaust archives consist of written records and spontaneous speech from oral history interviews, e.g., the Malach corpus (Byrne et al. 2004) is a large archive of about 8000 segments from interviews of Holocaust survivors, liberators, rescuers and witnesses. Question-answering system based on these archives is limited in terms of narrative immersion and user interaction.

We aim to create a rich experience which would replicate, as far as possible, the existing experience for visitors, by developing a virtual Holocaust survivor, who could effectively respond to questions in the closed domain of the Holocaust. The basis for the work was informed by research into conversational natural language interfaces.

## 18.2 Conversational Natural Language Interfaces

Conversational agents and natural language interfaces, a.k.a. chatbots, have been used to improve the communication between human and computers such as information retrieval systems. Chatbots can be text-based, speech-based or in the form of embodied agents.

Text-based conversational agents are the earliest form of chatbots. In a closed domain conversation, they sometimes fool users into believing that it is a real human through written conversation and applications of conversational programs vary from online help (interactive question answering), accessing an information system, to personalised services. The main areas involved to build conversational programs include natural language processing (NLP), dialogue management, knowledge representation (specialised and common sense knowledge), information retrieval and reasoning. Conversations with chatbots are virtually unlimited unless topics or tenors are restricted (closed domain). In the early years of Turing tests, it has been decided to add rules to limit the topic to a closed domain in order to give computers a chance. The most common method in closed domain conversations is searching algorithms based on question pattern and answer pairs in a repository of questions and answers. More recently, closed domain conversational systems started to integrate image-processing techniques to utilise multimedia data. For example, the COMPANIONS project (Wilks et al. 2011) resulted in a senior virtual companion who can engage the user in reminiscing conversations about their photographs using face recognition and information extraction techniques.

Speech-based chatbots are based on the automatic speech recognition (ASR), speech synthesis technology and test-based question-answering systems. Typical applications are in searching and personal assistant services such as Apple's Siri, Google Now, Microsoft Cortana and Amazon's Echo, which are embedded in smartphones, computers and game consoles. However, most of them only conglomerate data available on the Internet and lack sophisticated AI.

An embodied conversational agent (ECA) is a computer-generated virtual avatar that has a 2D or 3D representation and human-like behaviour whilst interacting with the user. Besides the back end of an ECA, i.e. a text-based conversational program, an ECA may involve visual/audio input and output components such as speech synthesis (output), voice recognition (input), animation for conversational behaviours such as gestures and facial expressions (output) and face/expression recognition (input). To date, ECAs have been widely used for various purposes: clinical psychology training (Talbot et al. 2012), museum and tour guides (Swartout et al. 2010), job interview skills training and coaching (Hoque et al. 2013), enhancing consumer experience in E-commerce (Delecroix et al. 2012), computer-assisted learning, etc., across many platforms—web-based, smartphones and online virtual environments such as Second Life.

### *18.2.1 Question Answering (QA) About the Holocaust*

Holocaust is a rare application domain for closed domain question answering in natural language processing (NLP). There are very few NLP applications dealing with questions about the Holocaust. Most of these QA systems are text-based information retrieval system though the corpus may be text, speech or videos in single language or cross-lingual. There is only one ongoing project (Artstein et al. 2014) allowing multimodal conversation based on video testimonies and spoken question answering, for which the production costs are high.

Previous Holocaust question-answering applications have been based on spontaneous speech from oral history interviews. For example, the Malach corpus contains 8000 segments from 300 interviews of Holocaust survivors, liberators, rescuers and witnesses. Each segment contains ASR outputs from IBM ASR systems with a 40% word error rate and automatically generated thesaurus terms and a set of human-generated data, including person names mentioned in the segment, thesaurus labels and three-sentence summaries.

## 18.3 Design and Development of *Interact*

At the outset, we established solid design principles, which informed the process and approaches throughout the project. These were (1) to recreate, preserve and replicate today's experience in the National Holocaust Centre (NHC) and (2) authenticate—to recreate the survivor's presence using non-interventionalist documentary techniques—and this is desirable in order to make the entire project more meaningful as a historical document.

### *18.3.1 Mapping Current Interaction*

The Holocaust is a predefined closed domain with words, phrases, people, places, ideas and testimonies that have been widely referenced, and the audience also brings a degree of knowledge of the domain with them. This domain is not static merely because the events happened in the past; new interpretations and discoveries happen all the time.

Each survivor overlays new areas of domain specific to their life experience, often in finer resolution than the general topic domain, for example, hometowns, siblings, birthday gifts and family events. In our case, a survivor talks about a decade of his life in enough detail to carry their message within usually 1 hour.

The duration of testimony and answers are roughly equal. That is to say that a fuller testimony (better defined and organised) will result in fewer questions due to fewer loose ends being left and that a scant testimony will leave many questions. When considering the application of this research and development to other programmes, the talk length needs to be carefully considered.

We believe that there is a penalty to the overall sum duration (it will increase) with short testimonies since there is a higher chance of exploratory questions, and those eventualities need to be provided for. In other words, the framework of the story is unclear and will be discovered by questions.

We worked on the principle that regardless of the fullness of the testimony, the audience will have questions for the survivor that either related to facts in his narrative or about his opinions, interpretations and emotions. Mathematically:

```
Duration of captured media = TM + NA +SA
```

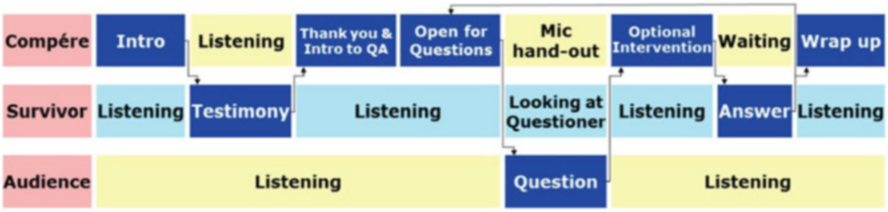


**Fig. 18.1** Interaction of Holocaust testimony and QA

where `TM` is the length of testimony, `NA` is answers relating to the narrative and `SA` is subjective answers.

```
NA = (1/TM) * Discovery Factor
```

When the narrative is badly defined due to a short testimony (`TM`), some of the questioning (`NA`) by the audience is spent on discovering the general facts of the story rather than probing more deeply into the survivor's experience and emotions.

Our decision on length of testimony was made to allow the survivors to talk for their natural duration, which is usually 1 hour and in some cases 40 min. Organisations seeking to consider applicability of this technology to other domains should be aware that these observations are only true for the Holocaust domain, which is large, representing huge swathes of human experience, and therefore our talk length and number of questions are correspondingly large. Smaller domains, such as an artist talking about a specific work, or an architect talking about a specific building, are likely to imply shorter talk lengths and fewer questions.

The current proceedings between museum visitors and survivors at the NHC happen as described in Fig. 18.1. The format is a typical talk-plus-QA session. Three parties, the facilitator, the survivor and the audience, are involved. Without the facilitator, the interaction does not work well. As host, the facilitator introduces the survivor, defines the periods when the audience should be listening and encourages the audience to interact. They also help to ensure fairness in giving as many of the audience as possible the chance to ask questions. We were only concerned with re-creating the active and passive engagement by the survivor, as the facilitator and the audience are real and present people.

The dark blue elements denote active engagement (talking); the light elements denote passive engagement (listening). In the cases of the facilitator and the audience, the passive and active engagements are *live* processes (they are living people); unlike in the case of the survivor, the active engagements can be replaced with linear pre-recorded sequences. The passive survivor engagements (light blue elements) are of indeterminate length and require special measures to replicate. We use a photorealistic 3D virtual human to replicate these stages.

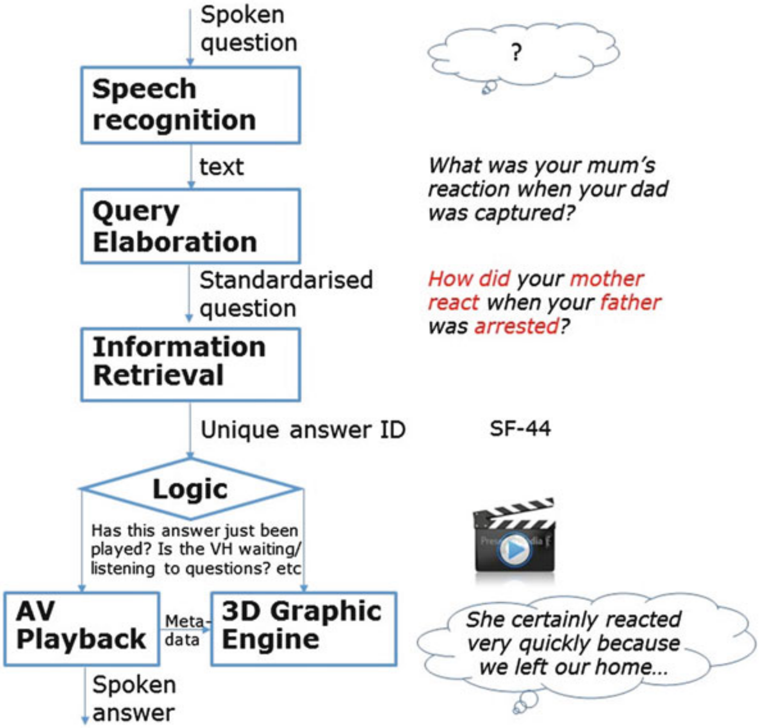


**Fig. 18.2** The flow chart of *Interact*

## *18.3.2 The Interact System*

Figure 18.2 shows how a question is processed and answered by the virtual survivor. The audience question is scanned in real time for recognised exchangeable terms; the same dictionary used to standardise pre-recorded questions is used to standardise the live audience queries. The information retrieval component uses a statistical relevance model to match the question to one of the QA pairs recorded with the survivor. If a selected answer (identified by a unique asset ID) passes the customer-defined threshold, the audio-visual assets associated with the ID are played back to the audience.

Regarding the technological development of the system elements, some components were developed based on third-party software, e.g. Nuance technology for speech recognition and NPCEditor (Leuski and Traum 2011) for information retrieval.

### 18.3.3 Question Generation Methodology

The NPCEditor requires us to define questions and answers as a pair. Semantic variants of the question are ignored during pre-production. Variants will be introduced later in the process, but when generating questions, we are looking for unique question-answer pairs, rather than different phrasings of the same question. For example, *Have you ever experienced survivor guilt?* and *Have you ever felt guilty for surviving when so many others perished?* are the same question, counted as one question and therefore asked once. However, *Have you forgiven the perpetrators?* and *Have you forgiven those involved?* are different questions, since the survivor may treat the perpetrators and those who did nothing or stood by as events unfolded differently. They are regarded as two distinct questions and both were asked.

We established two categories of question that can be posed: (1) questions that are specific to the survivor and his/her testimony, e.g. places, times, people, objects and events laid forth during the testimony. It would not be possible to ask this type of questions without having experienced the talk, (2) subjective questions. The audiences wish to know what view, opinion, interpretation or emotion the survivor attaches to any aspect of the domain, whether that be the domain defined during testimony or common-knowledge domains.

Below are the procedures created by the team to develop testimony-specific questions:

1. Survivor testimony was recorded as a guide. The video was trimmed, compressed and uploaded to the collaborative secure document system.
2. The testimony was transcribed and marked up to identify people, objects, events, times, places and digressions.
3. A lifeline chart was drawn up to include all mark-ups that could lead to a valid question.
4. A team was appointed, given the materials and asked to methodically go through each entry on the lifeline, generating questions as they go. On the whole, the nature of these questions is an attempt to increase the definition or resolution of the domain.
5. The survivor was asked selected questions to complete the domain and progress stories.
6. Further testimony-specific questions (second round) were generated based on 5.
7. Subjective questions were generated—questions that were related to feelings, opinions and views. These questions in general could be asked to any survivor.
8. The questions were collated, processed and approved by the team.
9. The questions were prioritised.

We use a lifeline chart (Fig. 18.3) to develop testimony-specific questions. This allows a group of people to navigate and visually view a life story. Its principle aim is to facilitate and enable question generation through group working. The Holocaust lifeline works on two common and basic principles, that survivors got older and were geographically displaced (e.g. by being moved from camp to camp,

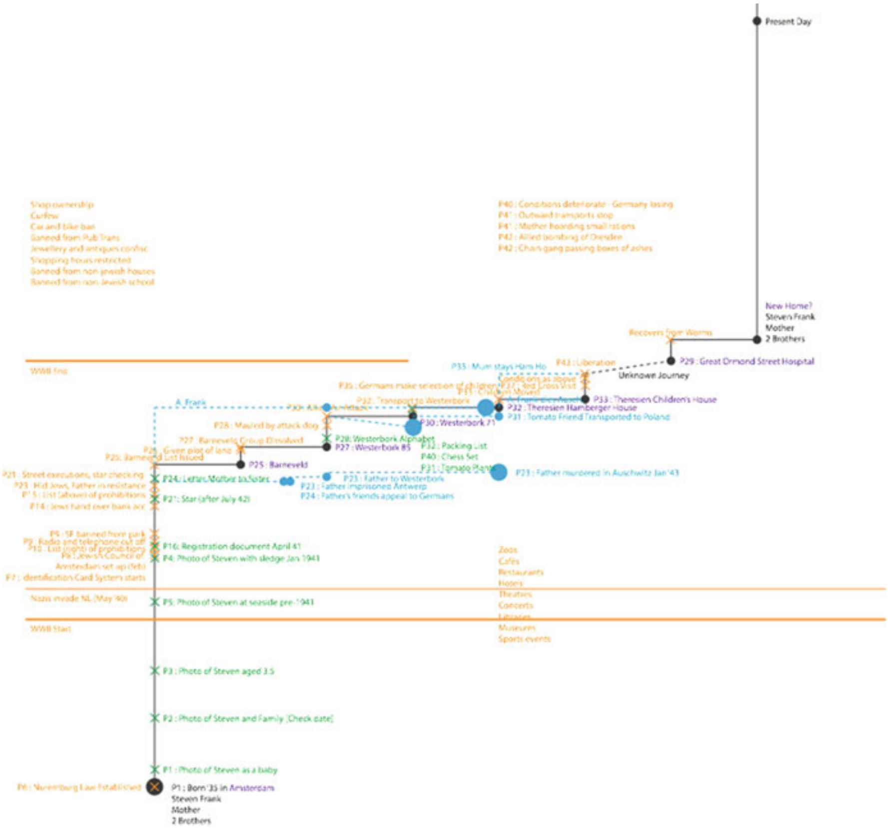


**Fig. 18.3** The lifeline chart of a Holocaust survivor

by changing location to seek to avoid persecution, by going into hiding). These two variables, age and displacement, represent two axes of the lifeline graph. Starting at the bottom left, the survivor was born in their hometown. As they grow older, they are displaced through various camps. Some survivors have extremely complex lifelines; others are relatively straightforward.

Storytelling and narration have played a significant role in Holocaust education and contemporary art, materialising as a trend that has developed alongside the increasing popularity of documentary practices in art. Storytelling seems to be capturing everyone's attention as an ever-increasing number of exhibitions feature strongly narrative work. We believe that our lifeline graph projected on time and displacement coordinate system are applicable not only to the Holocaust domain but also in wider narrative to define the *Hero's Journey* for documentary practices in art and exhibitions.

Testimony-specific questions were generated at all-day meetings with that sole purpose. The best question sets arise when many different perspectives are brought to the table, always remembering that the profile of the question-generation group should always be matched to the profile of the audience. Our sessions typically involved eight to ten people for each question-generation session.

Subjective question generation took place in the same forum, but with a different approach. An analysis of the questions asked by schoolchildren to the survivor, supplied by the Holocaust Centre, has led to the identification of a map of topic prompts. Distinctly different from the logical discovery of the domain through questions relating to the domain, the subjective questions seek to discover how the survivor in question felt at given times, how their faith was effected and how their interpretation or opinions may differ from the norm or the history books. Many of the questions are generic, but not all. Each mind-set is adopted by the question-generation group, as they aim to methodically predict as many subjective questions as possible.

At the time of writing, ten survivors' testimonies have been processed in this way, and the team generates approximately 550 subjective questions and 500 testimony-specific questions per survivor.

The question processing stage removes duplicate questions and stops words whilst not breaking up a grammatical sentence and standardises each question making it as succinct as possible and following a high standard of grammar.

### *18.3.4 Video Recording and 3D Data Capture*

Survivors were filmed over a 5-day period each at the studio. We trained the survivor to start and end each answer by looking straight into the camera, but to address the whole audience (our standby staff carefully placed around the studio), whilst they were giving the testimony and answers.

We use a stereo-pair camera and a facial close-up camera for video recording of testimony and answers and also photographic and facial scanning of the survivor for generating a 3D model of virtual human. Figures 18.4 and 18.5 show survivors giving their testimonies and answers in a filming session. In terms of audio I/O, we use stereo overhead, lapel mic and a microphone for the questioner.

A key principle of *Interact* is authenticity; the collected data will not be processed in any way. No grading, colouration or editing will take place other than to normalise the image. The captured data remains a primary source historical document. We adjusted the lighting and colour of the renders of 3D virtual human in the post-production and testing phase to match those in pre-recorded videos.

### *18.3.5 Creating Virtual Survivors*

In the interaction chart (Fig. 18.1), the active engagements (dark blue) of the survivor are linear pre-recorded sequences; the passive engagements (light blue)

**Fig. 18.4** Holocaust survivor giving his testimony

**Fig. 18.5** Video recording of a Holocaust survivor in the studio

are of indeterminate length and require CGI to replicate conversational behaviours like nodding, head tilting, gazing and other idle motions. To maintain the flow of the session, *Interact* virtualises the survivor during the passive engagements, i.e. we switch to a virtual 3D model of the survivor whilst he is not speaking.

The survivor's bodily pose at the beginning and end of each answer was recorded in metadata associated with the answer. Once an answer has been selected for

**Fig. 18.6** Photorealistic 3D representation of a Holocaust survivor

immediate display, the runtime application reads these poses and in real time configures the virtual survivor into those poses, cross-fading into the virtual survivor in-between answers. The virtual survivor continues to move naturally, based on a series of collected body language signatures. This means that neither the real nor virtual survivor has to return to a control position; they are free to move naturally.

The appearance of the virtual survivor is photorealistic (Fig. 18.6), but the main front studio light is switched off, so the survivor is slightly silhouetted. It acts as if the focus light has moved away from him/her. A key output of the virtualisation is that a fully detailed posable 3D model of the survivor is created. This will be of use to teams in the future looking to upgrade the experience for unforeseeable future display technologies.

The virtual survivor was created using a 3D laser scan as the basis; then a 3D modeller develops the model, using a large number of photographic reference images taken, whilst the survivor is in the studio. It was important that time was booked in to create this reference and that the survivor did not change their clothes during the week-long filming sessions.

### *18.3.6 The Uncanny Valley and a New Form of Mixed Reality*

A number of factors play important roles for user satisfaction when interacting with embodied conversational agents. These include personality, believability of non-verbal behaviours (e.g. facial expressions, lip synchronisation, gestures, body postures, gaze) and emotions, visual fidelity in terms of the appearance of virtual human and the naturalness of their motion and audio fidelity of synthesised voice (e.g. prosodic features of the utterance such as intonation, pauses, accent and stress).

Computer-generated (CG) virtual humans face another challenge, the uncanny valley (Brenton et al. 2005, Fig. 18.7), on appearance and movement of the animated

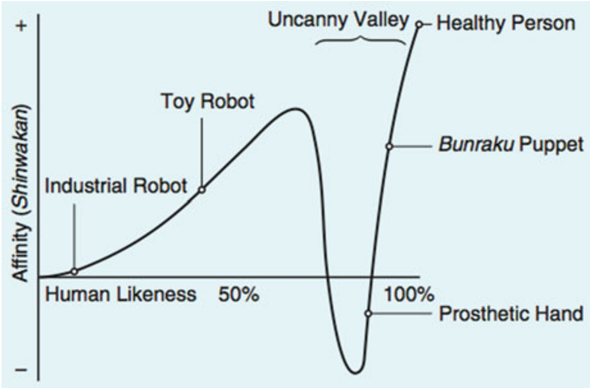


**Fig. 18.7** Uncanny valley (Brenton et al. 2005)

agent. The uncanny is a feeling of uneasiness triggered by unreal or unnatural artefacts of an animated character. The theory was originally developed for evaluating the realism of humanoid robots, but has been extended to animated characters. Unnaturalness in appearance is easily to be spotted when an embodied agent is in motion. For example, pandorabots' conversational agent Captain Kirk (Pandorabots.com), the user will soon discover the flaw on the texturing of his eyes and teeth when he is moving or talking. The problem is not obvious when Captain Kirk is still, but it immediately throws the users out of the flow of natural conversation once they noticed the nuance.

Since *Interact* is a mixed reality virtual human based on pre-recorded video testimony and 3D character generated from 3D scanning of real human, most of the above challenges can be avoided, if the transition between video recordings and photorealistic virtual human is seamless. The focus lighting approach is effective as it not only *hides* noticeable flaws of the CG character but also appears natural, i.e. when the survivor is not talking, the lights are dimmed.

Mixed reality, a.k.a. augmented reality, is defined as a live view of a physical, real-world environment whose elements are augmented by CG input. It usually overlays virtual components on real-world environment, creating an *augmented* reality scene (Milgram and Kishino 1994). As a result, the technology functions by enhancing one's current perception of reality.

We differentiate three forms of *mixed reality*, as illustrated in Fig. 18.8. The first is the most common form of augmented reality, where CG elements are overlaid on the real-world environment. The second form, which we call "time-based augmented reality", has multiple points in time overlaid onto the physical world environment. It often provides information about multiple points in time for a single object and has become popular in the construction industry for construction site monitoring and documentation.

The third form is what we defined as *mixed reality*, where instead of augmenting physical reality with virtual elements or past reality, it mixes physical reality and virtual reality at different points in time and transitions between them. The

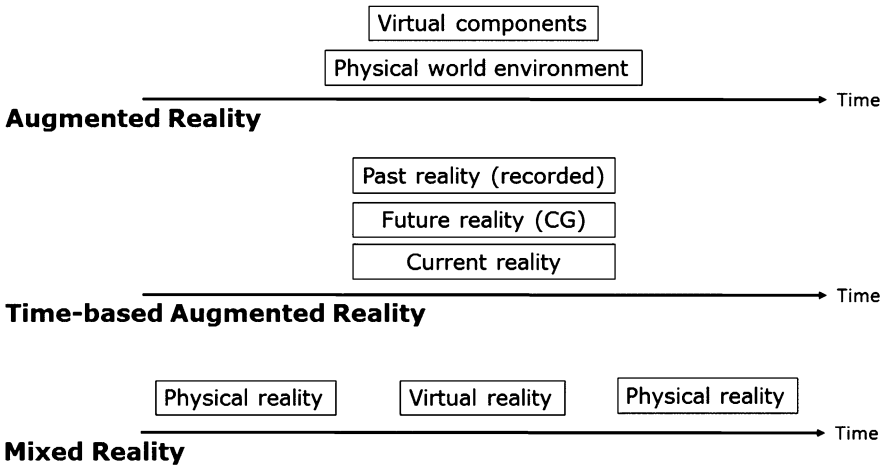


**Fig. 18.8** Three forms of augmented and mixed reality

components in the virtual reality replicate those in the physical reality using photorealistic rendering of automatically generated 3D models from laser scanning and photogrammetry data. The *Interact* project belongs to this category. We believe that combining blending techniques and focus lighting, the mixed reality could achieve the highest visual fidelity and it is the most promising media to overcome the uncanny valley.

### *18.3.7 Query Elaboration and Expansion*

User questions are processed at the lexical, syntactic and semantic levels. Discourse level analysis has not been considered due to the one-to-many conversation. It was evident that different types of query required the use of different strategies to find the answer. Typical question classes we considered were:

- Polar questions that seek to find one of two answers, typically yes or no
- Wh-questions (what, why, etc., which implies a range of possible answers)
- Questions that request description (usually with an imperative form of command, e.g. *how would you describe your school?*)

Topics in each question class were investigated, for example, wh-questions include names, age, opinion, fate (factual and hypothetical), reaction (factual and hypothetical), awareness, comparison, slow realisation, revelation, etc. The same information request can be expressed in various ways, some interrogative (*What are the names of x?*) and some assertive (*Tell me the name of x*).

The question expansion process developed accepts variant forms of each question and replaces them with its primary form based on a set of rules, including:

- Removing stop words in the question ("Did you *ever* go back to any of the camps"?), i.e. high-frequency common words that have a low weight and contribute little to the relevance score, such as *any*, *ever*, *always* and *specific*
- Using bare infinitive form of verbs in polar questions as the primary form ("Did your brother marry"?/"Did your brother get married"?)
- Accepting assertive forms of the question as secondary forms ("What was your daily routine in [x]"?/"Tell me your daily routine in [x]", "Can you tell me your daily routine in [x]"?)
- Accepting reverse questions, which does not have the wh-word at its beginning and is equivalent to a question that does, as secondary forms. ("What year were you deported to concentration camp"?/"You were deported to concentration camp in what year"?)

The semantic model of question understanding and processing would recognise equivalent questions, regardless of how they are presented. Due to the presence of a facilitator/compère (Fig. 18.1), a more complicated semantic model that would enable the translation of a complex question into a series of simpler questions, identify ambiguities and treat them in context or by interactive clarification is not required in this context. It is important to therefore recognise the importance of the facilitator in supporting the interaction.

A lexicon for the Holocaust domain was created in the query expansion process. The lexicon was built offline using pre-established rules to extract specialised semantic knowledge. Each entry consists a primary term and a number of secondary terms (exchangeable terms). When generating the ontology, we considered (1) English word frequency list based on the British National Corpus for conversational and task-oriented speech, (2) semantic relations for different parts of speech (examples in Table 18.1 are taken from transcripts of a survivor's testimony and answers) based on WordNet synsets (Fellbaum 1998) and (3) Holocaust domain-specific terms such as interchangeable place and names or names in other languages, e.g. *Theresienstadt/Theresien/ Terezin*.

In the lexicon, the primary word is a selected keyword or phrase in British English language. They make for very rigid forms of speech and carry the meaning of all the secondary forms, which is rich in slang, common speech, dialects and regional uses for words and phrases.

If a different territory showed an interest in hosting our virtual survivors, assuming that the principle language is English, any regional features of popular speech, spellings, words and phrases can be represented in the lexicon as secondary terms. Similarly, over decades, English language evolves; the lexicon could be updated to reflect shifts in the language.

**Table 18.1** Semantic relations of Holocaust-related words

| POS | Relations | Examples |
|---|---|---|
| Noun | Hypernyms—hyponyms | Flower—daffodil |
| | | Clothes—shoes, coat |
| | | Food—bread, porridge, potato |
| | | Building—barrack, house |
| | Meronym—holonym | Foot—toe, sole |
| | | Building—roof, attic |
| | Instance | Auschwitz—concentration camp |
| Verb | Troponym | Run—scarper, flee, escape |
| | Entailment | Beat—hit |
| | Derivationally related form | Remember—memory, recall, remembrance, recollection |
| | | Hate—hatred, hostile, dislike |
| | | Murder—kill, slay, execute, death |
| | Hypernym | Emotion—hate, love |
| Adj | Hyponym | Fear—scare, panic, dread, afraid |
| | Synonym | Downtrodden—oppressed, crushed, persecuted |

### *18.3.8 Interact Hardware*

Development and roll-out take place on any desktop or laptop computer built within the last 3 years. The installation hardware is a custom-integrated system designed to project 4k stereoscopic images onto a stage, complete with audio and parallel projection channels to support pre-recorded PowerPoint presentations and facial close-ups.

The system requires an integration service, but all elements are standard other than the facilitator's microphone which is a bespoke construction that integrates a momentary pushbutton into the microphone, allowing the facilitator to indicate when a question is being asked.

It is important to remember that the hardware requirements for our application are very high; more affordable systems can be enabled, for example, 4k resolution could be replaced by 1080p or 720p; stereoscopic 3D videos could be replaced by traditional 2D videos; projection could be replaced by screen-based display. As an illustration of the scalability of the technology, a 2D screen-based 720p implementation would run on an ordinary desktop computer.

## 18.4 Evaluation

*Interact* has been successful in demonstrating that integrated technologies can be applied to help audiences engage with key individuals who have unique knowledge or experience, providing the opportunity for people to engage with a pre-recorded filmed individual and virtual human to explore their experience. Experiments have been carried out to evaluate relevance of answers and user satisfaction.

Initial testing on the data set was performed using a body of questions authored by the United States Holocaust Memorial Museum (USHMM). The list contains sample questions for interviewing Holocaust survivors. The questions provided a framework for the kinds of question one may ask in an interview with a Holocaust survivor. The body of questions was useful to us because they are high quality and, more importantly, not written by any of the development team, therefore used a different style of language, important to our evaluation.

Our QA data set is asymmetric: The questions are short in comparison with the answers. The set had an average word count of 8.56 for questions, and an average answer word count of 114.48. The goal of *Interact* is to retrieve best-matching passages rather than short answers to questions, which is the goal of most information retrieval or question-answering systems currently do, e.g. the TREC question answering track that has motivated most recent research in the field focuses on fact-based, short-answer questions such as “Who killed Abraham Lincoln?”.

This led us to the idea that the statistical analysis of questions and the statistical analysis of answers should be different. We tested whole-word level scrutiny of the answers and sub-word (N-grams) scrutiny of the questions. The latter achieved strong results compared to symmetric or inverse-asymmetric scrutiny.

Sub-word scrutiny of questions exposed inconsistencies in our question data. For example, of the 913 questions, approximately 84 questions were of the same class, which was *Will you describe* .... In a small number of cases, when compiling the questions, we had slipped into using the form *Can you describe* .... During in-house testing, we found that using the latter form would improve NPCEditor’s precision on retrieval. We have never edited words from the survivor’s answer due to the requirement for authenticity, but we alter the stylistic form of the question as long as the meaning is maintained. We then replace the question with its primary alternate form based on the rules, e.g. *Can you tell us about X?/What was X like?*

Testing also exposed that the speech recogniser employed to semi-automatically transcribe the answers altered certain words against its internal look-up table. For example, the words “identity card” were abbreviated to “ID Card”. The abbreviation ID is not easily transposed to the word “identity” and its derivatives and therefore important connections were lost. We ensure that any such changes coming from the speech recogniser were identified and either rectified by either modifying the speech recogniser’s look-up table or our own data set. A similar observation was made about the notation of dates and years (e.g. nineteen forty-eight vs 1948).

The QA matching was capable of pulling deep answers out. Due to the asymmetry of the QA data set, the answer data includes more answers than the number of questions we asked, for example, asking about the professions of parents after the war and the favourite food of the survivor. Although we didn’t actually ask these questions in our video recording sessions, the answers were present inside the answer to another question and were successfully retrieved.

In the subjective evaluation, test subjects watched the filmed survivor giving his testimony, and then ask any question they liked. They gave a subjective rating to each response of the virtual survivor's on user satisfaction and quality of answers. The initial results showed a subjective rating of 4.2 for average user satisfaction and 4.08 for average quality of answers on a 5-level Likert scale.

Objective performance of precision, recall and quality of answers were measured on a relatively small testing data set. The definitions of these evaluation measures are below.

1. *Precision*: The fraction of retrieved instances that are relevant, i.e. proportion of relevant answers among all returned answers.
2. *Recall*: The fraction of relevant instances that are retrieved. Nonresponse is considered here. It is calculated by the number of relevant answers returned, divided by the total relevant answers in the data set. Since Interact only returns the best answer or no answer, the recall is calculated differently from conventional information retrieval system evaluation. For example, for ten user questions, Interact returned seven relevant answers, one irrelevant answer and two nonresponse. In the data set, we are able to find relevant answers for the two questions which returned an irrelevant answer or no answer. The recall will be $7/9 = 77.8\%$.
3. *Quality of answer* is measured by comparing *Interact* response with a real person's response. Of course, it might not be possible to compare virtual survivor's response with the real person whose answers were recorded, a team member who is very familiar with the survivor's story and scripts acted as the human evaluator. We compared the answers returned by *Interact* and the best answers given by the human evaluator using the existing answers in the data set and compared how close they are. In ten questions, if six are the same from *Interact* and from the human evaluator, then the human likeness or quality of answer is 60%. Those responses that are relevant to the question but not the best answer in the data set were not counted.

Our testing data set has 42 QA pairs. The system returned 31 relevant answers, 25 of them are the best answers in the data set; seven irrelevant answers, five of which have a better answer in the data set; and four nonanswers, two of which have a relevant answer in the data set. Therefore, the precision of Interact is 81.6%; the recall is 81.6%; and the quality of answer (human likeness) is 64.3%.

We are in the processing of collecting more data from the QA sessions at the National Holocaust Centre when the audience interact with the virtual survivors and plan to analyse the data on a much bigger test collection.

## 18.5 Conclusions and Future Work

We have presented a viable approach to creating a question-answering virtual human for educational use within Holocaust education. *Interact* provides a significant opportunity for Holocaust museums and centres to preserve this vital educational experience and continue using testimony to support museum-based learning, to ensure that museum visitors of the future are able to access an experience that would be lost to them without the project and to expand its audiences, by providing multiple opportunities to listen and interact with a survivor and providing access to the experience off-site in the future. Apart from applications within museum settings, *Interact* provides substantial opportunities for the wider arts sector to employ the model to create conversations between a pre-recorded photorealistic virtual human and audience. Future work should conduct experiments comparing a real Holocaust survivor with the virtual survivor over a video-conference interface like Skype, i.e. a new variation of the Turing test, in order to investigate and evaluate its impact on human-computer interaction.

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# Chapter 19
# A Driving Simulator Designed for the Care of Trucker Suffering from Post-Traumatic Stress Disorder

**Corentin Haidon, Adrien Ecrepont, Benoit Girard, and Bob-Antoine J. Menelas**

**Abstract** It appears that multiple factors may impact the mental and physical health of truckers. Moreover, victims of fatal injured accidents involving large trucks are mainly non-occupants of trucks. From these observations, it appears that truck drivers are likely to suffer from post-traumatic stress disorder (PTSD). Our work addresses this point. This chapter describes the realization of a truck simulator for the care of truckers suffering from PTSD. Our contribution concerns the development of a serious game (SG), for not only exposing the user but also offering a familiar environment inside which he can act in order to recover his ability to face the traumatic situation. We rely on two main axes to design such a game: (a) the game mechanics to allow the user to learn new associations to the stimuli related to the fear and (b) the personalization of the virtual environment.

**Keywords** Post-traumatic stress disorder • Truck simulator • Action-cue exposure therapy • Virtual reality therapy • Serious game • Gamification

## 19.1 Introduction

It is known that truckers do face multiples issues that may impact their psychological health. The ignorance of the route, the traffic, bad weather conditions, and the dangerousness of the cargo constitute indeed professional conditions that may cause this. In the same way, several personal conditions (remoteness of the family, physical

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health, fatigue, and loneliness) may also have negative consequences on a trucker. All this seems to create an environment conducive to accidents that may have major impacts for the trucker and the company.

In fact, the last update (June 2015) regarding the highway traffic reports that in 2013 large trucks represented 4% of all motor vehicles in the USA (NHTSA 2015). Nevertheless, trucks were involved in 9% of fatal crashes and 3% otherwise (crashes having injuries and/or property damages). Moreover, in fatal crashes, only 17% of the victims were occupants of large trucks. This means that a majority of truck drivers who had an accident are likely to face post-traumatic problems. However, to the best of our knowledge, there is no work that targets the treatment of truckers suffering from **post-traumatic stress disorder (PTSD)**. Our research intends to answer this need. In general, the research for the treatment of PTSD among victims of road accidents is very recent; the few studies done on this domain show nevertheless encouraging results (Wiederhold and Bouchard 2014). Our work is part of this niche. It concerns particularly accidents involving large trucks.

The use of virtual reality (VR) technologies in the fields of education, rehabilitation, and neuroscience is increasingly recognized (Menelas et al. 2009, 2014; Bohil et al. 2011; Botella et al. 2011; Otis and Menelas 2012). In particular, it was shown that for a majority of cases, the exploitation of VR tends to provide better results than traditional approaches because of their ecological validity (Girard et al. 2009; Bourgault et al. 2014) (an action is said ecological if it is similar to what happens in the daily life (Plantevin and Menelas 2014; Lavoie and Menelas 2016; Brassard et al. 2012; Menelas and Otis 2013)). However, the high cost in terms of development, usage, and maintenance tends to limit the use of VR. **Serious games** (**SG**: *games that do not have entertainment, enjoyment, or fun as their primary purpose* Michael and Chen (2005); Menelas and Otis (2012b)) turning on workstations appear to represent an alternative that may require a lower cost when compared to a VR system, although not being less effective Bouchard et al. (2012); Menelas and Otis (2012a). In this view, we have designed a SG that simulates the driving of a truck for the care of people suffering from PTSD using three key aspects. First the main characteristics of what is essential to a game are preserved, second the game mechanics are associated with some learning mechanics, and third several parameterizations are made available.

The paper is organized as follows: Related works are presented in Sect. 19.2, and the theoretical approach is detailed in Sect. 19.3. Section 19.4 describes the proposed simulator before the conclusion in Sect. 19.5.

## 19.2 Related Work

Undergoing an event where its physical or psychological integrity is threatened (war, terrorist attack, earthquake, traffic accident, etc.) may have major psychological impacts on a person. Beyond normal reactions (having hard time to sleep well and/or going over the details of the situation in its mind) that decrease with time, PTSD is a mental illness that can result from this particular event. PTSD appears to affect 6.8% of the USA (Garcia-Palacios et al. 2002), whether adults or children. Considering these statistics, the treatment of this mental disorder represents a major public health issue (Kessler et al. 2005).

Besides the use of some medications (antidepressants), **cue exposure therapy (CET)** offers an increasingly considered treatment. This approach amounts to gradually bring a person to face the stimuli that he is afraid of. This relies on the fact that fear is due to exaggerated physiological and behavioral responses to stimuli that are perceived as being more threatening than they actually are. The idea behind the CET is thus to decrease the fear sensation throughout a gradual exposition to the stimuli while letting the person being able to control his emotional reactions (Foa and Kozak 1986).

Although in vivo (real-life) exposition remains an effective solution, the exposure can also be assumed through pictures, films, or mental imagery deducted from descriptions of the fear-inducing stimuli (imaginary exposure) (Scozzari and Gamberini 2011). Nevertheless, in virtuo exposure is another way to expose user by the use of virtual reality, what has been defined by North (North et al. 1996) as **virtual reality therapy (VRT)**. VRT has proven especially useful when in vivo exposition may not be exploited (e.g., the patient may not be able to support a real-life exposition or the situation may be difficult to reproduce live) or when imaginary exposure is inefficient (e.g., because the person is not able to properly represent the source of anxiety in its mind) Wiederhold and Bouchard (2014) by ensuring the ability to create a suitable and safe environment for the patient. Several research areas as diverse as arachnophobia, agoraphobia, and obsessive compulsive disorders have shown the benefit of using an in virtuo exposition therapy (Carlin et al. 1997; Côté and Bouchard 2009; Garcia-Palacios et al. 2002; Meyerbröker and Emmelkamp 2010).

In addition, it should be noted that VR technologies allow to set up situations (a) that are interactive (the user may act on the environment) (Menelas et al. 2014; Menelas 2013; Menelas et al. 2010; Vézien et al. 2009), (b) that are dynamic (they can be paced by an external party, such as a therapist), (Garcia-Palacios et al. 2002; Menelas and Otis 2014; Menelas 2014), and (c) that meet the needs of each patient (the situation is close to what frightens the patient). Therefore, we consider that it would be appropriate to use VR in order to not only expose the user to the frightening situation but also let him recover the power to act inside this environment (on the truck in the present case). Doing so, the patient would be able to react differently in the traumatic situation. This approach is known as **action-cue exposure therapy (ACET)** (Girard et al. 2009). The following describes our theoretical approach in exploiting a virtual world in order to design an action-cue exposure therapy for truck drivers suffering from post-traumatic stress disorders.

## 19.3 Theoretical Approach for the Design of an Environment Guided by ACET

Our analysis of different works on VR technologies to cure PTSD revealed that the full potential of VR is rarely reached. Considering an application such as Virtual Iraq (Cukor et al. 2009), a simulator where soldiers could revive a series of war events, it is clear that this work has paved the way to a very innovative approach. However, the exploited simulator does not allow the patient to be fully active in the environment; it only delivers visual and auditory stimuli to the patient.

Our goal is rather on an active treatment of the user where he could try to correct his reactions, what will assess the success of controlling his anxiety. As a therapeutic-oriented solution and to allow the user to be an actor, we will design a truck-driving simulator that will also be a SG. This SG will be designed to teach (Marks 1978; Bíró 2014) the user new associations to the stimuli that activate the fear sensation as identified by Powers et al. (2007) as a way to overcome a trauma. For this, we rely on two axes to design a SG as efficient as possible: (a) the game elements that will support learning mechanisms and (b) the personalization of the virtual environment. But as a SG is before all a game, we take into account as well the characteristic elements of a game as described by Morford et al. (2014). The next subsection details the critical features of a game, its gamification, and the personalization inside the simulator.

### 19.3.1 Critical Game Features

Game elements are described by Morford et al. (2014) in their work as *critical features* of a game, following the theory of Tiemann and Markle (1985). They are defined as:

- *Direct impact on the outcome of the game and its results:* By interacting with the simulator, the player affects the final state of the game.
- *Clear goals and/or end conditions:* The player is given a mission to realize at each level of the game.
- *Rules and barriers:* Physical barriers limit the player during its mission; game rules compelled him "verbally."
- *Probabilistic outcome:* Randomness (tokens) affects the player.
- *Strategy development and heuristics:* The player has to build some strategies to overcome the obstacles of the game.
- *Noncoercive initiation:* The player is free to play whenever he wants to.

We adapt those *critical characteristics* to our simulator in order to define the key features of our game (Cf. Table 19.1).

Inside the simulator as well as in a real situation, the driver cannot control the phobic element: their appearance is randomized (probabilistic). Nevertheless,

**Table 19.1** Game characteristics of the simulator according to Morford et al. (2014) and associated examples

| Critical game features | Example |
|---|---|
| Direct impact on the outcome of the game and its results | Driving from point A to point B |
| Clear goals and/or end conditions | End condition reached when the destination is reached |
| Rules and barriers | Barriers: terrain<br>Rules: drive without crash turnaround |
| Probabilistic outcome | Meteorological conditions (rain, snow, etc.)<br>Traffic (artificial intelligence) |
| Strategy development and heuristics | Driving strategies (overtaking, etc.) |
| Noncoercive initiation | Voluntary patient |

a control user interface is provided to the supervisor, allowing him to make it appear whenever he desires to. Various items can be parameterized: light to dense traffic, specific weather, etc. By doing so, the simulator permit to gradually expose (Tybout et al. 2005) the player following two ways:

1. The distance between the phenomenon to the player
2. The intensity or duration of the phenomenon (snowfall or blizzard, etc.).

Once critical game features considered, we take into account serious game mechanics, game elements that define the aspect of a serious game.

### *19.3.2 Serious Game Mechanics of the Simulator*

To ensure a systematic approach over the game mechanics and their associated learning mechanisms, we analyzed the simulator using Arnab et al.'s *Learning Mechanics-Game Mechanics (LM-GM) model* (Arnab et al. 2015). The LM-GM model is a tool created as an answer to the lack of methodology in the creation of SGs and their assessment, thus it features a methodology to map learning and game mechanics in this particular case.

Through the observation of the game loop (see Fig. 19.1), six main groups of game mechanics (GMs) have been identified based on those provided by the LM-GM model:

Movement, Simulate / Response, and Realism[(1)] As a driving-oriented simulation, the core of the gameplay consists in driving, what relates to the *Movement* of the player inside the virtual world. The *Response* of the vehicle, as an immediate feedback, must remind the player the sensations experienced while driving in the real world, what leads to some *Realism* in the feedback.

Levels, Cascading Information, and Behavioral Momentum[(2)] The player experiences multiple sessions called *Levels*. Each level features a final objective (e.g.,


**Fig. 19.1** Game loop explicited with the LM-GM model

destination, driving goal, do not overturn, etc.). The organization of levels ensures *Cascading Information*, i.e., that the conditions evolve gradually to a situation more complex and closer to the traumatic situation. *Behavioral Momentum* is generated through the looping over levels.

Story and Information(3) The *Story* takes place in the job assignation during the game. *Information*s are created around the mission such as the type of load of the truck, the client to deliver, etc.

Tokens(4) *Tokens* are random elements (from the user perspective) that can affect the game state. In our case, tokens are controlled either by a random sequence or by the supervisor. Weather conditions, time of the day, and car crashes present on the road are an example of what can happen randomly during the play session. They are elements that will serve for the personalization of the game.

Feedback, Rewards, and Status(5) The main *Feedback* is given to the player at the end of a level so that he can assess his success or failure. Upon mission completion, the *Status* of the player is updated, and his experience will eventually increase. *Reward* mechanisms can then be mapped to the experience of the player. The simulation provides also immediate feedback described previously as Response.

Design / Editing(6) Although not being the main gameplay feature, we consider *Designing* the truck as an important factor to enhance the immersion and realism of the game. As explained earlier, our goal is to provide realistic and familiar surroundings to the player. By being able to customize the look of his truck, the player can identify the truck, hopefully leading to some positive reinforcement.

**Table 19.2** Game and learning mechanics of the simulator, based on the *LM-GM* model

| Game mechanic | Learning mechanic | Implementation |
|---|---|---|
| Movement, simulate/response, and realism(1) | Explore, simulation, and action/task | Immersion through a HMD and a *racing wheel* |
| Levels, cascading information, and behavioral momentum(2) | Repetition | Levels |
| Story and information(3) | Guidance and instructional | Radio messages & Level conditions (job given) |
| Tokens(4) | | World events: weather, daytime, car crashes |
| Feedback, rewards, and status(5) | Feedback and motivation | Level change, pop-up, and truck customization |
| Design/editing(6) | Ownership | Customization of the truck |

The GMs previously described have then been mapped to their associated learning mechanics (LMs):

Exploration, Simulation and Action / Task The user will learn through its *Exploration* of the world as well as the realistic *Simulation* of the truck that will respond to its *Actions*.

Repetition *Repetition* will play an important part of the learning process as it will activate the "over-learning" (Marks 1978) ability of the patient.

Guidance and Instructional Through mission aspects, the player will be *Guided* and receive *Instructions* on how to deal with his objectives.

Feedback and Motivation *Feedback* will be provided as indicators of the user progress, leading to potential *Motivation* to improve.

Ownership The sense of *Ownership* of the truck is designed to improve the player involvement in his mission.

All of those associations, as well as their implementation that will be discussed later, are summarized in Table 19.2. Finally, we will consider positive reinforcement in our work as a way to optimize the player experience and provide him a better recovery.

### *19.3.3 Positive Reinforcement Items*

A last part of our work has been focused on the items that can provide positive reinforcement to the user. Such items aim to diminish satiety (Morford et al. 2014) and provide a feeling of control and skill to the player as well as gratification. It is however important that such items or events are perceived as informative and not as constraining, leading to a sense of powerlessness (Deci et al. 1999).

Reward systems and user progress assessment become then privileged interfaces to extend motivation when the "cycle of challenge and reward is balanced"

(Csikszentmihalyi 1997). These interfaces represent items of the first two levels of game concepts according to (Deterding et al. 2011):

1. *Game interface design patterns* refer to design components assessing success such as badges or leaderboard, visual feedback, etc.
2. *Game design patterns and mechanics* include gameplay items, in our particular case narrative constraints (path) and truck commands (wheel).
3. *Game design principles and heuristics* contain "evaluative guidelines," such as objectives during the mission.
4. *Game models*, conceptual models, will be analyzed outside of the game through the medical monitoring of the player. Few of the game mechanics can assess the user experience, i.e., efficiency of the treatment; we rely on debriefing as well as medical clues (stress, tension, etc.) to do so.
5. Finally, *game design methods*, or practices and processes, will be held through user testing and treatment result analysis following them.

By developing a simulator, we have to ensure each of those items is added in a nonintrusive manner, in order not to diminish immersion or realism. This can be done by putting emphasis on the traveled distance (user progress), quick-displayed badges, or event praises Morris et al. (2013) through the truck radio (accomplishment) (see Fig. 19.2).

In the same way, narrative context can also be exploited as another simple option to explicit game objectives as well as immerse the player in a photo-realistic context. The radio is used as it would be by a transport company to transmit orders. For more details regarding the gamification of the designed truck-driving simulator, one can


**Fig. 19.2** Various items available: radio (*red*), badges (*yellow*), and GPS (*white*)

refer to Haidon et al. (2015). The narrative context can finally be customized for each user. We discuss this point in the next section.

### *19.3.4 Personalization of the Game*

We consider personalization, i.e., adapt the game to the user, as another important feature of the game. Aside from the game mechanics previously explained, personalization will act as a way to provide stimuli that may let the patient perceive the traumatic situation. To do so, we rely on the supervisor to adapt the game to the current mental state of the patient through the tools that are provided (scenario / map editor, etc.). This customization is materialized through two main aspects that are customizing: (a) the environment (visual) and (b) the missions. Doing so, we offer the trucker an opportunity to reactivate his capacities for driving a truck and thus be able to act differently in the traumatic situation.

Such customization will also allow the supervisor to control the difficulty of the game through a combination of road type (e.g., linear highway surrounded by forest, urban road, forest path) and the conditions that affect the levels: weather conditions, time of the day (affecting visibility and visual fatigue), car crash aside the road; the goal being to enable the patient to gradually approach and ultimately relive the situation that led to his trauma. The adaptation of the difficulty to the player has been recognized as a powerful learning component (Hanus and Fox 2015; Bíró 2014; Morris et al. 2013), and most games use formulas to calculate difficulty, whereas our approach is on a fully human-controlled shaping of the game experience.

### *19.3.5 Customization of the Missions*

As exposed by Biro et al., the ability to customize the missions allows the creation of a user-relative learning path (Bíró 2014), what we relate to as *therapy protocol*. To do so, the scenarios define the user experience via various customizable parameters through an adapted menu containing among others:

1. The type of road (forest-surrounded highway, urban road, woodland path, etc.)
2. Weather conditions (clean sky, rain, snow, wind, tempest, etc.)
3. Time of the day or the night (affecting visibility and eye strain)
4. Work on the road, car crash
5. Traffic density

An example of the provided parameters is described in Fig. 19.3.

Reviewing the conditions of the missions during the treatment, the patient is gradually exposed to more and more complex conditions, ultimately leading to the nearest situation possible to the one that brought the trauma. This process of adapting difficulty dynamically has been recognized as an efficient learning process


**Fig. 19.3** Scenario parametrization

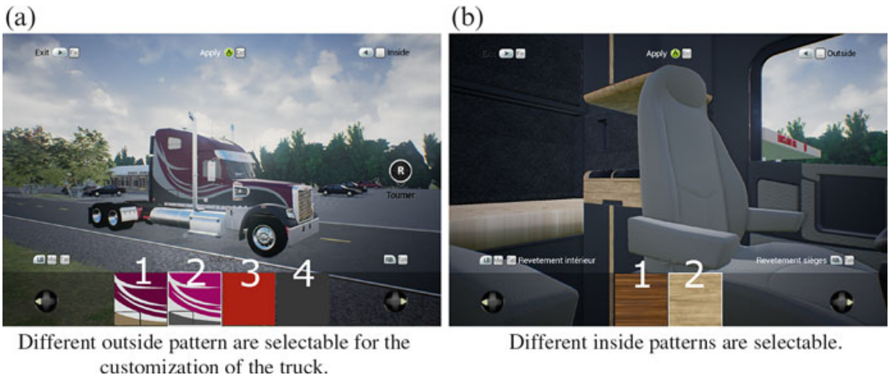


**Fig. 19.4** Customization of the truck (**a**) outside and (**b**) inside

(Hanus and Fox 2015; Bíró 2014; Morris et al. 2013), but where most of the games compute the difficulty through algorithms, our approach is to offer an estimation based on health expert advice.

### *19.3.6 Customization of the Truck*

Once the customization option unlocked, the user is able to change the design of his truck either its outside and inside parts (see Fig. 19.4). His choices are then associated with his profile. Giving the ability to edit the truck is used to bring the patient to express his attachment to his truck.

## 19.4 The Proposed Game

Previously mentioned elements (Table 19.2) led us to a design specially focused on the core game elements and the customization of an interactive photo-realistic environment created using the game editor *Unreal Engine 4*. The single-player game recreates the environment of the province of Quebec (Canada) in different weather conditions (sunny, snowy, rainy, and icy) and at any time of the day (sunrise, noon, afternoon) and night (see Fig. 19.5).

### *19.4.1 Setup Overview*

Different devices are available to the user to support the immersive nature of the system. One counts a *head-mounted display* for the visual modality and a *racing wheel*, a gearbox, and pedals equipped with haptic feedbacks to control the vehicle (see Fig. 19.6):

A head-mounted display (HMD)

Thanks to the HMD and the head-tracking system provided, the user has the ability to turn his head in order to fully appreciate the interior of its truck.


**Fig. 19.5** Weather condition samples. (**a**) Sunny day. (**b**) Rainy day. (**c**) Snowy day. (**d**) Rainy night

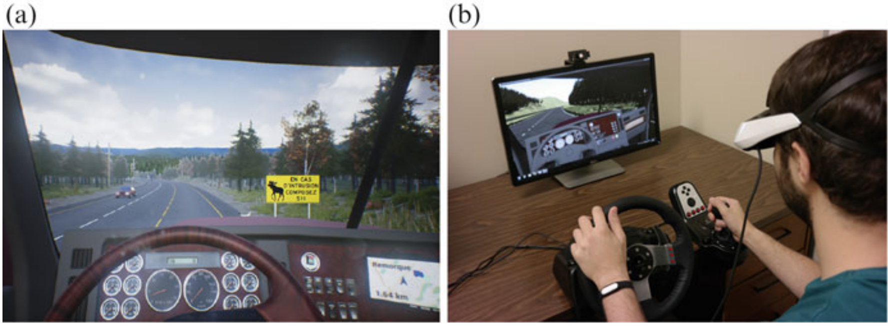

**Fig. 19.6** Current setup of the system. (**a**) Scene rendered through the HMD. (**b**) A user experimenting the game, the HMD on his head and the wheel in hands

This is particularly interesting, since it may reveal meaningful details about the dashboard meters and buttons. It also allows looking out the window and in the mirrors, providing a freedom of movement and a feeling of realism.

A set having a racing wheel, a gearbox, and pedals

Through the *Logitech G27 Racing Wheel*, the user is able to maneuver the truck (see Fig. 19.6). The steering wheel has a force feedback system, so it reacts to turns, shocks, and speed in the same way as power steering. The shift lever can be set to automatic, sequential, or manual mode. Different buttons, placed on the steering wheel and the gear lever, allow controlling the base functionality of the truck (headlights, turn signals, horn, radio, etc.). All these elements cause both a change in the vehicle behavior and are also highlighted by a faithful visual representation via the orientation of the steering wheel and indicators on the dashboard.

## *19.4.2 Gameplay Through the Therapy Protocol*

The therapy protocol that will be exploited with this interactive tool is a multi-session therapy (from 8 to 10). Although the second and later sessions being mostly identical, the first session is not made as a driving session but more as a discovery one.

### 19.4.2.1 The First Session

During the first session, the patient ends up in a parking lot where several types of trucks are stationed at reasonable distances. The patient can move at its own speed in that environment, allowing its progressive exposure and skills recovering. At this time, the patient is asked to choose its preferred model of truck from a selection of well-known trucks. His choices are then associated with its profile. This session will therefore be a first contact with the tool. It will allow to assess patient trauma level. Indeed, it is expected that patients with a high level of trauma may experience some difficulties in completing that session.

#### 19.4.2.2 Subsequent Sessions

During each other's session, the player operates the game by driving a preselected truck from one point to another as stated in his mission (see Fig. 19.3), previously set up by the supervisor. At any time in the mission, the doctor will be able to change the course of events through different shortcuts (e.g., reset the weather to clean) if he decides so.

At the start of a mission, a non-player character (NPC) will talk to the player through the radio of the truck. The narrative presentation used to transmit the job requirements and the conditions of the road aim to imitate a real job environment and support the immersion. While achieving special conditions (e.g., first 10 km traveled), the NPC will also transmit praises, completing the feeling of positive reinforcement (Morris et al. 2013).

By completing a mission, the player gets rewarded through new options to customize his truck, as well as badges. A first reward appears after a certain amount of completed missions, unblocking the customization option inside the game. Later, rewards are associated with the number of completed missions and traveled kilometers. At the time of this writing, no definitive computation formula has been decided, as it is still a work in progress.

Assessing the player through the game is a first step in the reinforcement process, the second step being done during a debriefing of the therapeutic session. Either having succeeded or failed or after the patient have asked to stop, the patient is invited to debrief about the activity outside of the game.

## 19.5 Experiments

Despite not being able to test the whole therapy protocol, we have driven some user tests to assess the game mechanisms and the added value of the reinforcement elements of the simulator. In this section, we discuss the protocol used and the results obtained during our tests.

### 19.5.1 Protocol

Despite each participant being interviewed a single time, two items are monitored jointly: the feeling of immersion and the satisfaction, or acceptance, of the participant.

In a first time, the participant is installed in front of the workstation linked to the different interaction devices described in the Sect. 19.4.1: wheel, pedalboard, HMD, head-tracking device, and headphones. Then, the participant is asked to adapt the setup to feel comfortable. The pedalboard can be pushed forward or backward, the HMD tighten or loosen, and its lenses displaced to adapt to the vision of the participant and provide the best clarity.

Next, the participant is asked to perform a driving mission as follows:

1. The participant goes from the starting point to a trailer and attach it to its truck
2. The participant transports the trailer to its destination
3. The participant places the trailer at a given location in reverse

Two groups have been selected for the test. Each group counts 10 and 11 participants, respectively. The first group performs the mission without reinforcement elements described in Sect. 19.3.3. The other group performs the same mission with those reinforcement elements. At the end of the mission, participants in the second group are also given the ability to customize the truck as explained in Sect. 19.3.6. After the game session, the participant is asked a few questions about his experience verbally and through various questionnaires. The tests are opened to any willing participant inside the University of Quebec at Chicoutimi (UQAC) fulfilling the following conditions:

1. Being student at the UQAC
2. Being in good health

No other criterion is applied. Each participant is provided an e-mail with all the information about the project as well as opened dates for the test. In total, 21 persons contributed to the experience. In this group, one counts 16 men and 5 women. The average age of participants is 22 years.

### 19.5.2 Satisfaction Test

The satisfaction test contained seven questions from 1 to 5, 1 being “Not at all” and 5 being “A lot.” The following were asked:

1. How much would you rate your experience during the game?
2. How much would you rate your implication in the success of the mission?
3. Did you feel like you were doing your best?

**Table 19.3** Results of the satisfaction form from 1 (unsatisfied) to 5 (fully satisfied)

| Participant | Satisfaction | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 4 | 3 | 4 | 5 | 5 | 4 | 4.14 |
| 2 | 2 | 4 | 5 | 5 | 3 | 4 | 3 | 3.71 |
| 3 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 3.71 |
| 4 | 4 | 5 | 4 | 5 | 4 | 4 | 3 | 4.14 |
| 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4.71 |
| 6 | 4 | 5 | 4 | 4 | 4 | 4 | 4 | 4.14 |
| 7 | 4 | 4 | 3 | 2 | 3 | 3 | 4 | 3.29 |
| 8 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 4.29 |
| 9 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5.00 |
| 10 | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 3.57 |
| Group 1 average | 4.00 | 4.40 | 4.00 | 4.10 | 4.00 | 4.20 | 3.80 | 4.07 |
| 11 | 5 | 4 | 4 | 4 | 3 | 4 | 4 | 4.00 |
| 12 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 4.86 |
| 13 | 5 | 4 | 3 | 4 | 4 | 4 | 4 | 4.00 |
| 14 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 3.71 |
| 15 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4.43 |
| 16 | 2 | 3 | 3 | 2 | 2 | 3 | 3 | 2.57 |
| 17 | 4 | 4 | 3 | 4 | 3 | 3 | 3 | 3.43 |
| 18 | 4 | 5 | 5 | 3 | 2 | 2 | 4 | 3.57 |
| 19 | 4 | 2 | 4 | 2 | 3 | 2 | 4 | 3.00 |
| 20 | 4 | 4 | 3 | 4 | 4 | 5 | 5 | 4.14 |
| 21 | 5 | 4 | 4 | 4 | 5 | 5 | 4 | 4.43 |
| Group 2 average | 4.27 | 4.00 | 3.82 | 3.64 | 3.45 | 3.64 | 4.00 | 3.83 |
| Global average | 4.14 | 4.20 | 3.91 | 3.87 | 3.73 | 3.92 | 3.90 | 3.95 |

4. Did you feel challenged by the mission?
5. Were you stimulated by the goals of the mission?
6. Did you feel a sense of accomplishment at the end of the mission?
7. At what point did you feel the game suited to your expectations?

The answers of the participants are reported in the Table 19.3.

Two main observations can be done. On one hand, with a global mean of 3.95 points, the satisfaction is globally good for all of the participants. On the other hand, the satisfaction is inferior by 0.24 point (6%) for the second group. Such a difference is not significant and point out the overall inefficiency of the reinforcement elements. It is important to shade this result as most of the reinforcement elements were still at an early development stage at the time of the tests as well as limited in usefulness for a single session (e.g., the customization). Overall, this research shows that satisfaction is already correct, but the reinforcement elements lack deepening.

### *19.5.3 Immersion test*

The immersion test contained nine questions from 1 to 5. In this scale, 1 corresponds to a weak immersion, whereas 5 represents the optimal immersion. The following questions were asked:

1. How much did the game hold your attention?
2. How much did you feel concentrated in the game?
3. How much effort did you provide during the game?
4. Did you feel like doing your best?
5. How much did you lose the sense of time?
6. How much were you conscious of being in the real world while playing?
7. How much did you forget your everyday concerns?
8. How much were you aware of yourself and your surroundings?
9. How much were you aware of the events taking place around you?

The answer of the participants are summarized in the Table 19.3.

With a mean of 3.66 points, the immersion is judged as correct for most of the participants. We observe that with a mean greater by 0.15 point for the second group, the reinforcement elements did not worsen the immersion provided by the game. A special effort has to be done for the immersion; the interviews have highlighted a sensibility and latency concern for the head tracking, the sensibility considered too high for a game. However, returns show that the realism of the visual and the sounds of the environment helped to immerse the player in the game (Table 19.4).

### *19.5.4 Cybersickness Test*

A last noticeable topic was the cybersickness. Cybersickness are notably due to the latency between the visual cue and the kinesthetic cue (McCauley and Sharkey 1992; LaViola 2000). In our case, the vision will indicate a movement where the body stays immobile. The more the player is immersed, the less cybersickness can happen. Moreover, if the movements of the player inside the game match with his movements outside the game, cybersickness diminishes. A quiz of 16 questions marked from 1 to 4 has been given to the participants, 1 meaning that the symptom asked has not been felt and 4 that the symptom has been severally felt (Table 19.5). The following points were proposed:

With a mean of 1.45 point, cybersickness is well contained inside the simulator. It is however important to observe that the studied population contained a majority of young people, often in contact with video games although rarely with virtual reality. Such a population could have developed a better tolerance; more diversified populations could be more representative (Table 19.6).

**Table 19.4** Results of the immersion form from 1 (not immersed) to 5 (fully immersed)

| Participant | Immersion | | | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 5 | 5 | 4 | 4 | 3 | 5 | 3 | 3 | 4.00 |
| 2 | 4 | 5 | 5 | 5 | 3 | 1 | 1 | 3 | 4 | 3.44 |
| 3 | 4 | 5 | 5 | 4 | 5 | 3 | 5 | 2 | 3 | 4.00 |
| 4 | 4 | 4 | 5 | 4 | 2 | 3 | 5 | 2 | 2 | 3.44 |
| 5 | 3 | 5 | 5 | 4 | 5 | 4 | 5 | 3 | 2 | 4.00 |
| 6 | 5 | 5 | 3 | 4 | 1 | 2 | 4 | 2 | 2 | 3.11 |
| 7 | 4 | 5 | 4 | 4 | 5 | 3 | 4 | 1 | 2 | 3.56 |
| 8 | 4 | 5 | 2 | 4 | 3 | 4 | 4 | 4 | 3 | 3.67 |
| 9 | 5 | 5 | 5 | 5 | 3 | 2 | 4 | 1 | 3 | 3.67 |
| 10 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3.00 |
| Group 1 average | 4.00 | 4.70 | 4.20 | 4.10 | 3.40 | 2.80 | 4.00 | 2.40 | 2.70 | 3.59 |
| 11 | 4 | 5 | 4 | 4 | 2 | 4 | 4 | 3 | 4 | 3.78 |
| 12 | 5 | 3 | 4 | 5 | 4 | 5 | 5 | 2 | 1 | 3.78 |
| 13 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 1 | 3 | 4.00 |
| 14 | 5 | 4 | 4 | 3 | 4 | 4 | 5 | 2 | 4 | 3.89 |
| 15 | 5 | 5 | 4 | 4 | 4 | 3 | 4 | 2 | 4 | 3.89 |
| 16 | 3 | 3 | 3 | 3 | 5 | 2 | 5 | 4 | 4 | 3.56 |
| 17 | 3 | 3 | 4 | 3 | 4 | 2 | 3 | 3 | 2 | 3.00 |
| 18 | 3 | 5 | 5 | 5 | 2 | 3 | 4 | 5 | 2 | 3.78 |
| 19 | 4 | 5 | 4 | 5 | 3 | 3 | 5 | 4 | 4 | 4.11 |
| 20 | 4 | 5 | 3 | 3 | 5 | 2 | 5 | 4 | 5 | 4.00 |
| 21 | 3 | 3 | 5 | 4 | 4 | 4 | 5 | 1 | 1 | 3.33 |
| Group 2 average | 4.00 | 4.18 | 4.00 | 3.91 | 3.73 | 3.36 | 4.55 | 2.82 | 3.09 | 3.74 |
| Global average | 4.00 | 4.44 | 4.10 | 4.00 | 3.56 | 3.08 | 4.27 | 2.61 | 2.90 | 3.66 |

**Table 19.5** Summarize the results obtained with the participants

| General discomfort | Fatigue | Headache |
|---|---|---|
| Eyestrain | Difficulty focusing | Increased salivation |
| Sweating | Nauseas | Difficulty concentrating |
| Sense of heavy head | Blurred vision | Light-headedness opened eyes |
| Light-headedness closed eyes | Giddiness | Stomach disorders |
| Burps | | |

## 19.6 Conclusion and Future Work

This chapter described the design of a simulator for truckers suffering from PTSD. For this, we used VR technologies in order to not only expose the user to the frightening situation but also let him recover his power to act in this environment. The proposed design relies on a theoretical approach centered on two elements that are detailed: the core game elements of the simulator and the personalization of the

**Table 19.6** Cybersickness form results from 1 (no symptom) to 4 (strong symptom)

| Participant | Cybersickness | | | | | | | | | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 1 | 1 | 2 | 3 | 1 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 1.56 |
| 2 | N/A | | | | | | | | | | | | | | | | N/A |
| 3 | 3 | 3 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1.63 |
| 4 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.19 |
| 5 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1.31 |
| 6 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 1.25 |
| 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.00 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.06 |
| 9 | 3 | 2 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 1.56 |
| 10 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1.31 |
| Group 1 mean | 1.78 | 1.33 | 1.22 | 1.33 | 1.78 | 1.00 | 1.22 | 1.33 | 1.33 | 1.67 | 1.56 | 1.11 | 1.11 | 1.22 | 1.11 | 1.00 | 1.32 |
| 11 | 2 | 3 | 1 | 3 | 2 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 1 | 1 | 1 | 1 | 1.63 |
| 12 | 2 | 3 | 2 | 4 | 2 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1.75 |
| 13 | 3 | 3 | 4 | 1 | 3 | 1 | 3 | 4 | 2 | 3 | 3 | 1 | 1 | 2 | 4 | 1 | 2.44 |
| 14 | 2 | 2 | 3 | 2 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 1.69 |
| 15 | 2 | 2 | 3 | 2 | 2 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1.56 |
| 16 | 1 | 2 | 1 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.31 |
| 17 | 2 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1.50 |
| 18 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 1 | 4 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 2.06 |
| 19 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.31 |
| 20 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.00 |
| 21 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 3 | 2 | 1 | 1 | 1 | 1 | 1.38 |
| Group 2 mean | 1.73 | 2.00 | 1.91 | 1.82 | 2.00 | 1.09 | 1.64 | 1.27 | 1.91 | 2.00 | 1.64 | 1.45 | 1.18 | 1.36 | 1.45 | 1.18 | 1.60 |
| | 1.75 | 1.67 | 1.57 | 1.58 | 1.89 | 1.05 | 1.43 | 1.30 | 1.62 | 1.83 | 1.60 | 1.28 | 1.15 | 1.29 | 1.28 | 1.09 | 1.46 |

game, validated by new models. We have reported here some tests realized in order to assess the game mechanisms and the added value of the reinforcement elements of the designed simulator.

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# Chapter 20
# Using Serious Games to Establish a Dialogue Between Designers and Citizens in Participatory Design

## The Architectural Portal of People's Narratives

**Danilo Di Mascio and Ruth Dalton**

**Abstract** The use of serious games in participatory design activities in architecture and planning has received growing attention in recent years. Their alternative ways of representing and communicating information have the potential to make the learning process more interesting and playful and hence more effective. This book chapter presents an alternative way to establish a dialogue between designers and citizens and raise citizens' awareness of the urban environment and its architectural representation through the creation of an 'Architectural Portal of People's Narratives' using a game engine. The research presents a theoretical, methodological and technical approach. The literature review includes definitions of participatory design and related issues, the use of 3D city models as participatory tools, 3d representations of city in videogames, and serious games as participatory tools. The final part of the chapter deals with the main points of the development process of the virtual Grainger Street (Newcastle upon Tyne, UK).

**Keywords** Participatory design • Videogames • 3D representation • Narrative • Architecture • Urban design • Virtual environment • Game engines

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## 20.1 Introduction

The development and use of serious games, and related theories and tools, in participatory design activities in architecture and planning has received growing attention in recent years. This is due to the fact that their alternative way of representing and communicating information has the potential to make the learning process more interesting and playful and hence more effective. The connection between videogames and urban design and planning is not new. In fact, for a number of years now, a remarkable number of videogames, such as SimCity (Maxis 1989), have been inspired by (and possibly have inspired) urban design/planning activities. Applications of serious games can be already found in a wide number of fields including cultural heritage, engineering, education and training and healthcare (Ma 2011). There are also several examples using serious games and game technologies in architecture and urban planning, including utilizing them for participatory design activities (Poplin 2011), the focus of this chapter. However, some of the projects are mainly focused on simply visualizing an urban design scheme (Indraprastha and Shinozaki 2009). The majority of design proposals visualized by using these technologies are also primarily developed by urban designers or architectural professionals, so people are asked to provide their thoughts only on a later stage; in other words the 'participatory' aspect of the 'serious game' is post hoc rather than concurrent. For example, O'Coil and Doughty (2004) created a virtual environment with the aim of improving the communication of a design proposal to residents of Hull; this game environment was displayed during a design workshop after which comments were solicited (O'Coil and Dougthty 2004). Other serious games can be more design oriented, such as the B3 Game (Poplin 2014, 2011) and 'Block by block' (UN-Habitat and Mojang 2014); in both games people are asked to 'play' at designing public spaces. Despite all of these excellent examples, the role that serious games can play in improving the interaction and communication between designers and citizens during the participatory design process is still under explored. Designers and citizens both have a central role in participatory design activities, but because of their different knowledge and ways of thinking, effective communication between them is frequently challenging. Typically lay people don't have proper knowledge (education and skills) to participate in these participatory design activities (Granath 2001). This book chapter presents an alternative way to establish a dialogue between designers and citizens and raise citizens' awareness of the urban environment and its architectural representation through the creation of an *Architectural Portal of People's Narratives* using a game engine. Moreover, it also aims to raise designers' awareness of people's experiences of the urban environment, which can then be fed back into the design process, whilst still at an early stage. The research presents a theoretical, methodological and technical approach.

The first section of this chapter will present the underlying, background research and assumptions behind this work; the literature review includes definitions of participatory design and related issues, the use of 3D city models as participatory tools, 3D representations of city in videogames and serious games as participatory tools. In the second part of the chapter, a theoretical framework and a methodology will be presented. The final part of the chapter deals with a case study: Grainger Street, Newcastle upon Tyne in the UK. In the last section, some of the main points of the development process of the virtual Grainger Street, from the data collection to the digital reconstruction and import in unity will be described.

## 20.2 Literature Review

Considering the purpose of this research, three main areas of interest have been identified accordingly: first, issues relating to participation; second, 3D representations of the city; and, last, the related use of videogames. Although, at a first glance, these three fields can be seen as separate domains, their intersections with each other generate three additional, highly relevant subareas of research, namely: 3D models as participatory tools, 3D representations of cities in videogames and the use of serious games as participatory tools (Fig. 20.1). This latter field of investigation is the one where the research described in this chapter is primarily located; however, the other categories in Fig. 20.1 are also of relevance to this research.

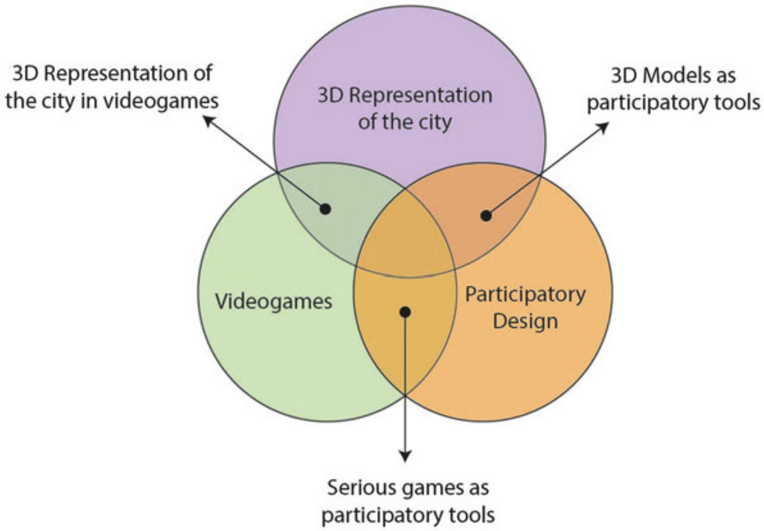


**Fig. 20.1** Diagram that shows the areas of interest, in particular the ones resulted by the intersection of the three main areas, investigated in the literature review (Image source: personal archive of the authors)

### *20.2.1 Participatory Design: Definitions and Issues*

> *Tell me and I'll forget; show me and I may remember; involve me and I'll understand.* (Chinese proverb)

Before defining a theoretical approach, it is important to understand the common issues in participatory design. A large number of the buildings and public spaces built in the UK and Europe after the Second World War followed the principles of the Modern Movement and, since then, have generated discontent and criticism by both architects and citizens. Architecture, designed with those principles in mind, was often found to be alienating, elitist, meaningless and boring especially because of their emphasis on functionality and reduced focus on, or total elimination of, any form of decoration/ornamentation. This generated a public reaction against, and later opportunities to renew, such postwar schemes that ultimately led to the introduction of participatory practices in architecture. Until that time, the design of the city was solely the prerogative of professionals (architects, planners, etc.) who, most of the time, just tried to envisage people's needs and desires. Several initiatives were developed around the concept of participation, such as the creation of the Community Architecture Group (Wates and Knevitt 1987) and the first academic conference in 'Design Participation' in 1971 which explored the meaning of participation in design and the importance and role of users in the process. The event was managed by the Design Research Society (DRS) (Cross 1972). The main purpose of participation, in the field of architecture and urban studies, is to actively engage the end users in the design process, where all stakeholders are involved. Hence, it is about not designing *for* people but *with* people; the preferable models are co-design and co-creation. However, the word 'participation' can assume different meanings if put next to other words, such as design participation, public participation and community participation. In each of these terms, the role of the key contributors to the process, designers,[1] users and communities, and the ways in which they interact with each other, may vary considerably (Lee 2006). However Lee (ibid) appropriates the concepts of 'abstract space' and 'concrete space' introduced by Lefebvre (1991) and suggests that the 'realm of collaboration' may exist only where the abstract and concrete spaces overlap, namely, in the act of 'Design Participation'. Abstract space is defined as the space in which architects and designers design cities and it is characterized by vision and geometry; in contrast, concrete space is the one in which people live and experience (Lee 2006). Phenomenologists defined this latter space as 'lifeworld' –

> i.e., the ordinary, everyday taken-for-granted experiences, events, and worlds within the building or associated with the building (e.g., the world of sidewalks, streets, and neighbourhoods surrounding the building). Phenomenologists study buildings as lifeworlds and ask, for example, whether a building's design supports or undermines the building's function, or whether a building's users make use of the building in the ways the architect envisioned (Seamon 2016).

[1]In this piece of writing, designer is used in a broad sense, so it identifies architects, urban designers, etc.

It is evident that architects/designers versus users/communities have different knowledge about the urban environment, and this introduces the first, and maybe the most important, challenge that occurs during participatory activities, namely, issues of clear communication between professionals and laymen (Tenbrink et al. 2014).

### *20.2.2 3D City Models as Participatory Tools*

In recent years, a wider penetration and availability of digital technologies and increasingly powerful computers (Moore 1965) have fostered the application of 3D city models in architecture, urban design and planning and related participatory activities. It is clear that 2D maps and plan views are inadequate for the process of understanding and design complex urban environments. This observation is valid, not only for laymen but also for professionals that need multiple representational techniques (which cover different scales, details and levels of information) to evaluate/design any project. For this reason, and thanks to the increasing computational power of computers, the interest in, and the number of, projects utilizing 3D city models has increased considerably. Urban environments are morphologically and visually complex and representations that use the third dimension can be essential to make them intelligible. 3D models that can be freely rotated and observed from various points of view have already demonstrated their benefits in the evaluation of 'spatial characteristics, design constraints and visual contexts' (Horne 2005). Hence, the usefulness of 3D city models is now being understood by many more institutions and professionals around the world, who are using them as design, planning and management tools (Horne et al. 2007).

DEMO:POLIS was an exhibition that took place in Berlin in 2016 about citizen's rights to public, urban space. As part of that exhibition, a specially designed virtual city installation was created, based upon the CityEngine software (and using the 3D planning model provided the Senatsverwaltung für Stadtentwicklung und Umwelt). Using this installation, visitors to the exhibition could redesign Alexanderplatz, a square in Berlin, based on their judgements of the proportion of open/public space to build space and of landscaped/green space within the public space, the density and heights of surrounding buildings as well as their uses (residential, commercial, cultural or mixed), etc. Each individual 'vison' of the Alexanderplatz is saved and stored and can be used to determine an amalgamated solution based on the average decision of all visitors to the exhibition (Dalton et al. 2016).

### *20.2.3 3D Representation of City in Videogames*

Cities have been exciting and evocative settings for many videogames. Real and fictional cities have been represented in this media in several ways; it is possible to

**Fig. 20.2** An in-game screenshot of City 17 from Half Life 2 (Valve 2004) (Image source: personal archive of the authors)

find virtual versions of real environments such as in The Getaway (Sony 2002) or totally fictional cities such as City 17 (Fig. 20.2) in Half Life 2 (Valve 2004) or City of Glass in Mirror's Edge (Electronic Arts 2008).

For the purpose of this study, it is useful to consider these virtual urban environments in two main ways. The first one is related to the way a player can interact with the virtual city. The interaction between the player and the city influences the representational characteristics of the virtual setting.

In SimCity (Maxis 1989), and in general, in all videogames that belong to the genre of City-building games (other relevant examples are Cities XL (Monte Cristo 2009), Tropico (Kalypso Media 2009), the player acts as a sort of omniscient and omnipotent mayor that plans, creates and manages every aspect of the city from its infrastructure (roads, highways, rails, power and water systems) to its buildings. The main objective of this kind of game is to create a big and prosperous city environment that satisfies its citizens. City-building games need representations that allow the player/major to check and manage large portions of the city in a single screen. For this reason, a typical point of view is from a far distance (albeit with the possibility to zoom in and out). The first SimCity used a bi-dimensional top view, whilst the last version of the game, released in 2013, employs a freely rotatable, full 3D, representation. Obviously the level of detail is directly related to the functionality of such a representation (and the level of detail of the most recent game has only been achievable through massive increases in processing power).

In other games, such as the Grand Theft Auto (GTA) V (Rockstar Games 2013), The Getaway (Sony 2002), Half Life 2 (Valve 2004) or Mirror's Edge (Electronic Arts 2008), the player controls one character whose available actions and his/her way of interacting with the virtual urban environment are heavily influenced by narrative and gameplay choices. These games tend to be action/adventure oriented: the virtual character can walk, run, hide, drive, talk with other characters and even fight (in some games). The city environments can be an open world (GTA) or a closed world (Mirror's Edge). In the former, the player can free roam around the city and complete a series of quests in no particular order; in the latter the player is required to complete one or more quests in a limited setting (or game level) that can be a single neighbourhood or an urban area. In these games the city can be explored using a first (Mirror's edge) or a third person point of view (GTA); the first simulate a point of view as seen in the reality from a person's eye, whilst the latter usually sees the character controlled by the player from behind. The attention to detail in these virtual cities is generally high; it is common to include a wide variety of elements such as street furniture and buildings. It is evident that interactivity and immersion in City-building games and first/third person action/adventures are completely different and as a consequence, the quality and quantity of details and their representational style affect players' interest and immersion in the virtual environment.

### *20.2.4 Serious Games as Participatory Tool (ca. 350 Words)*

The meaning of the expression 'serious games' has already been widely explored in other additional publications such as Ma et al. (2011). The definition of serious games includes all those videogame assets, such as game technologies or game design concepts, which have purposes, such as learning and training, different from the sole entertainment (Sawyer, 2007, cited in Djaouti et al. 2011, p. 27). The definition includes also game technologies, for example, game engines, and game design concepts. Benefits in the applications of serious games can be already found in a wide number of fields including cultural heritage, engineering, education and training and healthcare (Ma 2011). There are also several examples of using serious games and game technologies in the field of architecture (Lehtinen 2002; Hoon and Kehoe 2003; Richens and Trinder 1999) and urban planning, including being used for participatory design activities (Poplin 2011, 2014; Reinart and Poplin 2014; Engagement Game Lab 2010). City-building games cannot be included in this category because even if people can learn something about design/planning whilst playing them (i.e. in planning a city using SimCity), their primary aim remains entertainment. For the purpose of this study, we look at serious games and game technologies applied to design/planning activities, focusing only on game that present 3D representations of the urban realm. These games can be divided, to some extent, into two main categories. The first is about the use of game engines mainly for visualization purposes. For example, O'Coil and Dougthty (2004) created a virtual environment with the aim of improving the communication of a design proposal to residents of Hull; this game environment was displayed during a design workshop after which comments were solicited O' and Doughty (2004). In another research project, the game Unity[2] (Unity Technologies 2016) has been used for both visualization and interaction purposes; the user's interaction with game objects is examined as a way of improving the users' comprehension of spatial characteristics of the urban environment (Indraprastha and Shinozaki 2009).

In the second category, there are games used for more design-oriented purposes. In the B3 Game, citizens of Billstedt (Germany) were involved in the redesign of the town square. The game provided them the opportunity of selecting and adding street furniture objects (such as benches, lights and trees) and to (re)arrange the position of these elements around the 2D and 3D virtual representations of the square; the game allowed participants to share and vote for each design solution, improving the communication between citizens and planners (Poplin 2011). 'Block by block' (UN-Habitat, Mojang 2014) represents a serious application of the Minecraft videogame (Mojang 2011) in a partnership between Mojang (the game's makers), UN-Habitat (United Nations Human Settlements Programme) and the UN agency promoting sustainable towns and cities (UN-Habitat, Mojang 2014). In this initiative, young people can be engaged in the redesign of urban public space using Minecraft that allows them to create any kind of structure made by small cubes/blocks. A series of workshops have been planned to redesign ca. 300 public spaces in various countries worldwide (e.g. Mexico, Nepal, India, Peru) by 2016; the event hold at Aldea Digital, in Mexico, proved to be a big success (UN-Habitat, Mojang 2014).

## 20.3 Theoretical Framework: A Virtual Architectural Narrative Environment as Participatory Tool

### *20.3.1 From Participatory Issues to Research Questions*

Five main issues that influence the interaction between designers and users in participatory design activities have been identified.

- *Communication issues*: Communication can be interpreted, in this context, in many different ways; it can be heavily influenced by the initiator, experts or citizens or by both sides at the same time (and in various ways). Observing the recent consultation process of a street (located in Newcastle upon Tyne) confirmed that the well-known issue of communication between designers and citizens is a persistent issue. The representation of the project primarily used technical drawings, particularly a plan view, where both the proposed design and the current situation were overlaid on a single drawing without any graphical means, for example, different colours and lines widths, used to differentiate

[2] List of the software packages mentioned in the book chapter (the developers in brackets): Unity (Unity Technologies); Autodesk 3ds Max (Autodesk); Adobe Photoshop (Adobe Systems); Rhinoceros 3D (Robert McNeel & Associates); Unreal Engine (Epic Games); CryEngine (Crytek).

the two plans, making them practically unreadable. The overall view was quite confusing; plan, and other common views usually used in architectural and urban design are abstract representations and these drawings can limit the extent to which lay people can contribute to a participatory process. The communication issues directly relate to the visual tools used during the design process. A proper communication is also essential to build consensus (Wates and Knevitt 1987).

- *Content issues*: Usually, the content addresses the choice of tools and communication methods. However, a predefined graphical language (and related tools), used in architecture and related disciplines, already exists and this can't be ignored. According to Granath (2001) users are not properly prepared for being involved in a participatory design process; 'The point of departure for their conceptions of the future is often limited to the existing situation with its restrictions and possibilities. Being asked about what they want, they may have problems conceptualizing their wishes, articulating them even to themselves and even more communicating them to colleagues' (Granath 2001). As stated above, users' knowledge is situated in the concrete space of their life and experience or, as mentioned above according to the phenomenologists, 'lifeworld' (Seamon 2016). On the contrary, designers are used to working with abstract knowledge. Also Albrect (1988) states that because of the different knowledge and values of designers, (he refers specifically to architects but it can be generalized), and other people involved, reaching a genuine understanding may be problematic. In line with Norouzi et al. (2014), the client's lack of knowledge in the architectural domain represents the major difficulty with respect to increasing design quality and client satisfaction. On the other hand, designers often lack the everyday life experience of a specific area, which can be an invaluable input into design solutions.
- *Tools*: The use of appropriate tools during participatory design meetings can improve the communication between users and experts and hence the whole design process. In Ahn and Park (2007) more graphical information, representing materials, people's activities and colours, were used to make plan views more understandable by citizens. Ahn and Park also describe the benefit of a model, their *paper kit for park design*, used during a design workshop and developed in order to allow participants to explore design options and constraints of a specific public space (Ahn and Park 2007).
- *Role*: One way of avoiding miscommunication is represented by a clear definition of the roles of designer and citizen during the design process. In design participation, both designers and end users have an equal and central role, whilst in public participation and community participation, the main decisions are taken by the experts and users, respectively (Lee 2006). In the collaborative environment of design participation, both experts and users bring and share their specific knowledge. Sometimes participatory design can give the misleading impression that the role of citizens should dominate over the experts' role, whilst both contribute with important knowledge. Giancarlo De Carlo, Italian architect and pioneer of participation in architecture during the 1960s (De Carlo 2012), argued that the role of the architect in participatory design processes should increase;

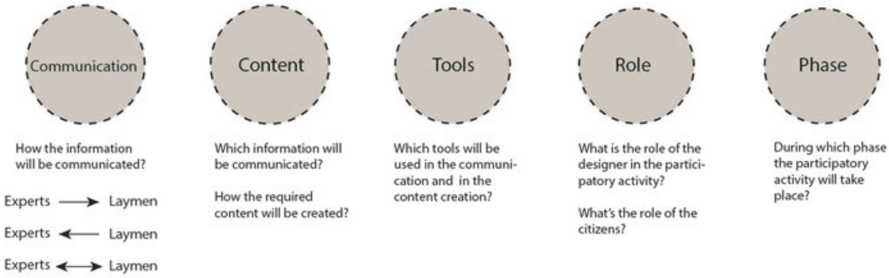


**Fig. 20.3** The five main areas and related issues generated by the interaction between experts and lay people during participatory design activities (Image source: personal archive of the authors)

it has the opportunity of bringing the architecture to the people (De Carlo 2013). Designers can facilitate people's comprehension of urban environments and design issues communicating information in a more accessible way and raising people's awareness about architecture, urban design and related disciplines. As already mentioned before citing Granath (2001), citizens alone can even find it difficult to articulate their needs and wishes, so elaborating a design solution can be even more challenging.

- *Phase*: Each phase of a project requires a specific content, particular ways of communication and the clear definition of participant's role. When and how citizens will be engaged in the design process is crucial. In the Transport Development Process defined by Newcastle City Council and applied to proposals for a new street layout in Newcastle (the participatory event described above), comprehensive public engagement appears only during 'Stage 3 – Refine the scheme through engagement'; the early design stage is mainly undertaken within the Council (Newcastle City Council 2016). Another option would be to engage people in the earlier phase of a project.

All these issues are summarized in the following scheme (Fig. 20.3).

### 20.3.2 Architectural Portal of People's Narratives

A possible way to reply to the issues described above is to create an 'Architectural Portal of People's Narratives'. This expression identifies a virtual navigable environment (created using a game engine) that presents both a particular care in the architectural representation of the urban environment and people's narratives about the place in the form of interactive elements (audio and visual). This tool will constitute a common ground of dialogue between designers and citizens, where they can share/exchange their knowledge about a specific area of the city, learn from each other and start further collective conversations. These exchanges of thought can be useful in informing subsequent design proposals or simply to start thinking about how to improve specific aspects of a selected neighbourhood or area.

#### 20.3.2.1 Phase, Communication and Tools

It would be very beneficial to engage people in any preliminary design phases as co-designers. However, because of their frequent lack of expertise in the architectural domain, a better option would be to engage them in even earlier design phases. In architecture and related disciplines, before starting to produce any design proposals, it is essential to undertake a form of site analysis. Every place is different and contains specific tangible and intangible features such as forms, materials, dimensions, architectural styles, colours, lighting, shadows, physical traces of past use or meanings attached to buildings or events. All these features represent parameters that can limit or inspire design solutions. The tangible and intangible characteristics that can be mapped are wide. 'The mapping needs to include physical aspects of the site, but also more qualitative aspects of the experience and personal interpretations of the place' (Farrelly 2007). Various techniques to record them exist such as drawings, physical models, written and oral narratives. Hence, the idea of this research is to use the Architectural Portal of Narratives during the site analysis, and so it can be used before, as well as in preparation of, the (co-)design phase.

The main issue that the Architectural Portal of People's Narrative tries to address is around the relationship between communication and content. As opposed to architects and urban designers, citizens verbally exchange ideas and thoughts daily since it is the oldest way of communicating. As previously stated, experts' ways of communicating design proposals is often obscure to laymen. Hence, the first objective to facilitate a dialogue between them is to allow people to understand the urban environment through drawings and models. Together with drawings, models (both physical and virtual) represent another essential tool to analyse a site and develop design solutions. In general, models are more intelligible than drawings; this explains their large use in the past by famous architects to present their designs to important clients, such as in the Renaissance period (Murray 1963). Undoubtedly, 3D digital city models can be very helpful in improving the communication and stimulating ideas and collective conversations, but there are also some aspects that can be pointed out. Most of them are massing models (namely, representations that show shapes and sizes of the urban environment without further details, such as building facades) that are very useful to provide an overview of a large area using a bird's eye perspective. However, in general, they represent buildings in a purely abstract way so people need to imagine all the rest by themselves; obviously this can generate confusion. In fact, it would be difficult to understand the scale of buildings (e.g. floor height), their functions and accessibility and then compare them to all the other elements of the urban environments. Therefore, a reflection is linked with the detail, namely, the quantity of visual information presented in a model. Another reflection is linked with the point of view. Bird's eye perspectives are useful to have overall views of large areas but people don't experience cities and architecture from the top. An apparently well-organized plan view can generate a dysfunctional building or public space. This is why architects use more than one representational technique. Moreover, buildings are always experienced from a human scale and perspective. For this reasons, the Architectural Portal of People's Narratives will be based upon a navigable 3D virtual environment using a game engine, where people will be able to freely navigate using a first person point of view.

#### 20.3.2.2 Content, Immersion and Playfulness

Another issue is related to the content. People's understanding of 3D representations of buildings and urban environments can be facilitated by designing a virtual navigable architectural environment of an existing place that citizens are familiar with. The adjective 'architectural' means that a particular care of architectural details is essential for two reasons: first, citizens can familiarize with schematic 3D representations of architectural elements and 3D navigation; second, a detailed 3D virtual environment increases people's interest, immersion and engagement during the virtual walk making more enjoyable, playful and effective experiences; this consideration is based on players' immersion in interesting and graphically rich videogame virtual environments. Playfulness can be expressed in many ways, also only with narrative and an interesting virtual environment. For example, in the videogame 'Dear Esther' (The Chinese Room 2012), the main game design idea was built around a mysterious story set in an atmospheric and lavish 3D environment that represented an uninhabited island in the Hebrides (The Chinese Room 2012, 2016). In this game there are no puzzles or actions apart from exploration and reading. In many adventure games, which present immersive 3D virtual environments, the players start to learn more about the story and the virtual place by exploring it and reading the textual information that can be discovered and collected from various locations. Exploration and reading textual information that unveil storylines are also presented in games where action, such as fighting, is one of the main characteristics of gameplay.

Exploration, reading and listening of stories can also be motivated by the curiosity of knowing more. Furthermore, the virtual location can also include relevant historical information. The environment should present sufficient details to allow people to recognize, to some extent, the real setting. Moreover, it should also foster immersion and concentration. Game engines allow the re-/creation of 3D virtual environments that can be explored using a first person perspective and in real time. Such virtual walks provide experiences of space and freedom of movement closer to reality than any via other medium (Di Mascio 2010). Hence, movement and point of views are not constrained to predefined paths. On the other hand, people can share their narratives, such as stories and memories linked to or about a specific place. Hence, in the context of this research, the role of the urban design experts, such as architects, is to create a virtual architectural environment using a game engine whilst the role of people is to provide their memories and stories that will populate it (Fig. 20.4). This exchange of content has the potential to foster a mutual


**Fig. 20.4** Diagram that highlights the contribution and exchange of knowledge between experts and citizens in the creation of the Architectural Portal of People's Narratives (Image source: personal archive of the authors)

learning approach: people can improve their awareness of the urban environment and their understanding of 3D architectural visualizations and spaces; architects and designers in general can learn more about a specific place by listening to citizens' narratives based on their direct experience of the place. In this way the Architectural Portal of Narratives would support a better understanding of an urban area by both sides.

## 20.4 Case Study: Grainger Street

### *20.4.1 Background (Cities, MyPlace and the Age-Friendly City Initiative)*

Cities are the most complex objects made by mankind and the number of people that lives inside these complex systems is growing exponentially. In the World Urbanization Prospects, it is stated that by 2050, 66% of the world population will live in urban areas (United Nations Department of Economic 2015) and the number will increase over time. But this doesn't represent the sole problem. In fact, these numbers will affect the demography of every big city and consequently its functions, shape and size will need to be (re)adapted accordingly. It is not rare to find, in any city, new public spaces that are completely empty, desolate and alienating. This issue has been highlighted by the World Health Organization (WHO) whose Global Age-Friendly City Initiative emphasizes the need to improve access for individuals, families, communities and the general publics to create places where they can comfortably live, grow up and grow old (World Health Organization 2007). This research forms part of a case study entitled *Narrative Urban Environments* that is part of a multidisciplinary research project called MyPlace: Mobility and Place for the Age-Friendly City Environment (Open Lab 2015). MyPlace is a three-year interdisciplinary and collaborative research project between Newcastle University, Northumbria University, Newcastle City Council and Newcastle's Age-Friendly City Initiative. The project is investigating how Newcastle upon Tyne can become an Age-Friendly City through research, planning and design activities that consider

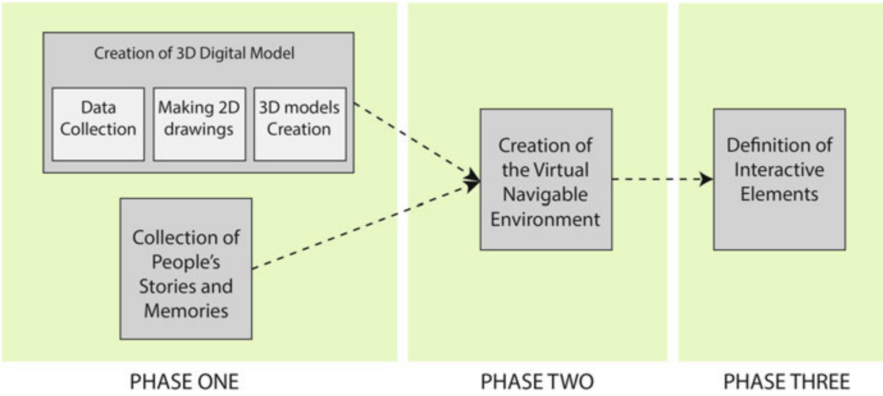


**Fig. 20.5** The three main methodological phases (Image source: personal archive of the authors)

or involve citizens in different ways. The WHO identified eight domains of an Age-Friendly City. The Narrative Urban Environments case study connects with the Age-Friendly City Initiative in three key areas, namely, participation, urban life and the built environment (outdoor space and buildings). Participatory activities, addressed at the production and shaping of urban life, are recognized as relevant for an active ageing and the urban environment is the first of the eight domains of an Age-Friendly City (Handler 2014). These points address some important questions that this piece of writing investigates, namely: how can citizens participate in the production and shaping of the urban life without having an expert understanding of the urban environment; how a virtual environment can represent a common ground that facilitates communication between designers and citizens.

### *20.4.2 Methodology*

The methodology that has been developed consists of three main phases (Fig. 20.5), each divided into further subphases. The data collection phase includes research about the historical background of the city (or parts of it), laser scanning, photographic survey and the production of sketches and schemes to facilitate a deeper understanding of the urban environment and its relevant elements and features.

### *20.4.3 Grainger Street: Historical Background*

As a case study, Grainger Street, one of the main historical streets in Newcastle upon Tyne (UK), has been chosen; the street is a key area hence, and many citizens can associate their experiences, stories and memories to it. Grainger Street was created as part of a big redevelopment project of the central area of the city during the nineteenth century, thanks to the vision and efforts of Richard Grainger (1797–1861) (Faulkner and Greg 2001), builder and developer, from which the road takes the name. The area that includes the street is called Grainger Town and has a high architectural and historical value. It was designed by the architect John Dobson, considered the best architect in the North of England during his time, in collaboration with other architects (Faulkner and Greg 2001).

The street connects Newcastle's Central Station with Grey's Monument, an important landmark in the city, in addition to being considered to be the city centre. The length of the street is about 550 m. From the station up to the Monument, Grainger Street is uphill and makes a slight curve on the right-hand side. The street is lined with remarkable pieces of Georgian and Victorian architecture: the area close to Grey's Monument is Neoclassical, as is the whole area redeveloped by Richard Grainger, whilst Victorian architecture can be found closer to Central Station which is Neoclassical. Some of the buildings have outstanding decorations and details such as cornices, columns, arches and mullioned windows. Most of the buildings have three or four stories and have multiple uses, typically shops on ground floors and residential dwellings on the upper floors. Besides these mixed-use buildings, there is a church (St. John the Baptist), with its oblique position which interrupts the sequence of the façades, and Grainger Market, the historical market of the city, another important element of Grainger's scheme. Unfortunately along the street, there are also a couple of later buildings of lesser architectural merit, built during modern times. The majority of the street is accessible to vehicles with the exclusion of the area closest to Grey's Monument and another one close to central Station, both of which have been pedestrianized.

### *20.4.4 Laser Scanning of the Street*

Laser scanning technologies were selected as an appropriate way to collect the basic data (in this case point cloud data) that we used as the basis to make a 3D digital model of Grainger Street. The point cloud data allows us to model with accurate dimensional references. The scanning phase of the project focused on the façades of the buildings lining the street and required the placement of 11 scanning stations and hence 11 distinct scans (Fig. 20.6). The process followed a zigzag line; this technique of alternating between right and left pavements/sidewalks has been useful to collect information on the upper portion of the façade of the buildings (difficult to gather with the scanner positioned close to a facade) as well as the standard façade data. Once the raw data were collected, the eleven scans were registered and any noise in the data removed. The street is always very busy; the number of pedestrians and vehicle is typically very high. This situation created not only noise in the scan data but also missing portions of the scanned façades. To create more manageable files, the original high-resolution 360-degree views were down-sampled and each scan compartmentalized into nine or ten smaller portions. In this way it

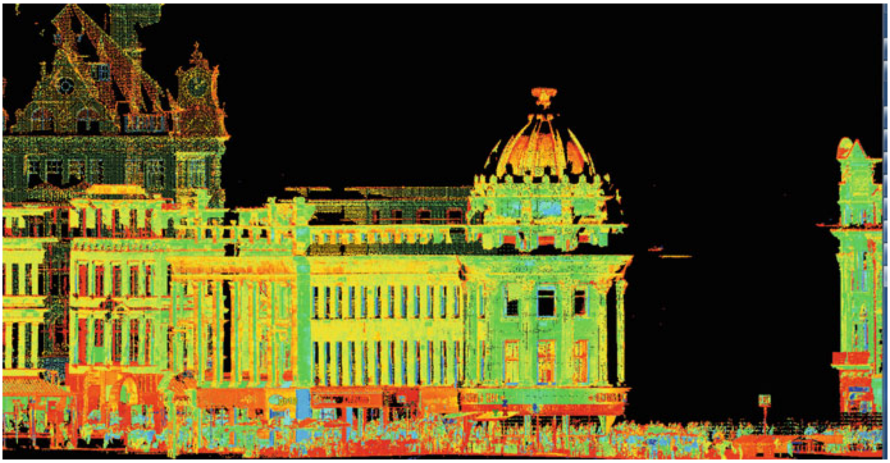

**Fig. 20.6** Image of a small portion of the point cloud (Image source: personal archive of the authors)

has been possible to import the data into 3D modelling software. The point clouds share the same coordinate system so when imported each of them will automatically position in the correct spatial location in relation to the other data. The files were then exported in various formats: pts., ptx and xyz[3].

### *20.4.5 Digital Reconstruction*

The digital reconstruction process took place in three phases: the organization of the files and facades, the schematic redrawing of the facades and the modelling of the facades and the street.

The first phase, the organization of files, has been particularly important. Before starting the redrawing and modelling work, each portion of each scan was numbered and attributed to one or more facades that in turn were assigned numbers as well. In total, 25 facades were selected to be modelled and the numbering starts from the central station (facade number 1) up to monument and it proceeds clockwise. All the redrawing and modelling processes have been divided into 11 separate files, like the scans. However, in each file, portions that are related to more than one scan have been imported, according to the facades to be modelled. In fact, the metric information of most of the single facades has been captured from two different scanning stations.

[3]These files extensions are related to point cloud data and present information about points' coordinates.

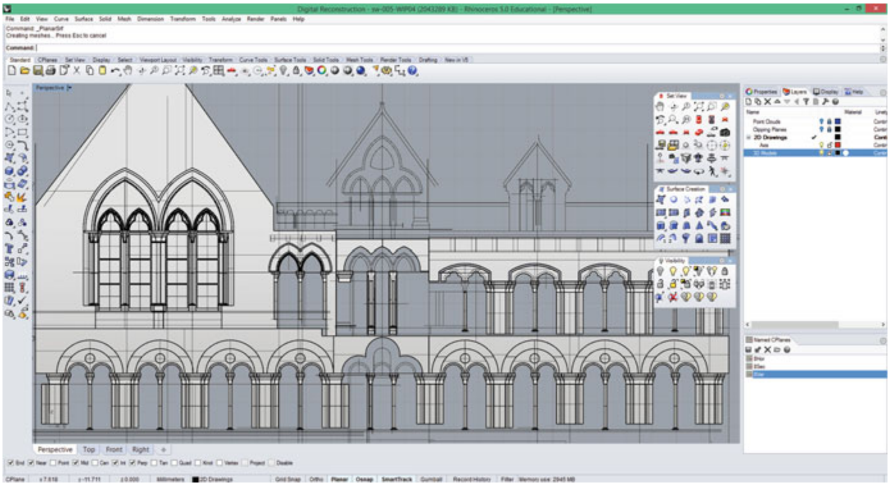

**Fig. 20.7** Redrawing and 3D modelling process of a facade (Image source: personal archive of the authors)

During the second phase, the point cloud data was used as metrically accurate references to redraw the elevations of the 25 buildings (Fig. 20.7); this redrawing process is still ongoing. The facades' shapes and details have been simplified and were considered more appropriate: in historic buildings all similar elements, such as columns or windows, are slightly different from each other, but the creation of a 3D navigable environment requires also to regularize and standardize them to save both time and memory usage.

After some tests with file formats, the point clouds were imported in Rhinoceros in .xyz format. This CAAD software was chosen because it provides a wide range of flexible and powerful tools for both 2D drafting and 3D modelling compared to pure 3D modeller. In Rhino, the elevations have been redrawn in vector format. Photographic surveys and sketches have been useful to understand missing parts of the point clouds and simplify complex geometries and decorations. Considering the complexity and density of each group of point clouds, and the overlapping of the facades positioned on both sides of the street in plan views, one of the two sides has been hidden accordingly using clipping planes. When necessary, also portions of the same facade have been hidden.

The 2D vector drawings have been used as a base to create the 3D elements that have been modelled using several techniques such as surfaces creation and various methods of extrusion. Also during the process of digital 3D modelling, clipping planes where used to hide portions of the facades. Using the same technique, it has been possible to draw relevant sections/profiles that gave further information about the depth of the elements of the facades. The digital reconstruction process is still ongoing (Fig. 20.8).

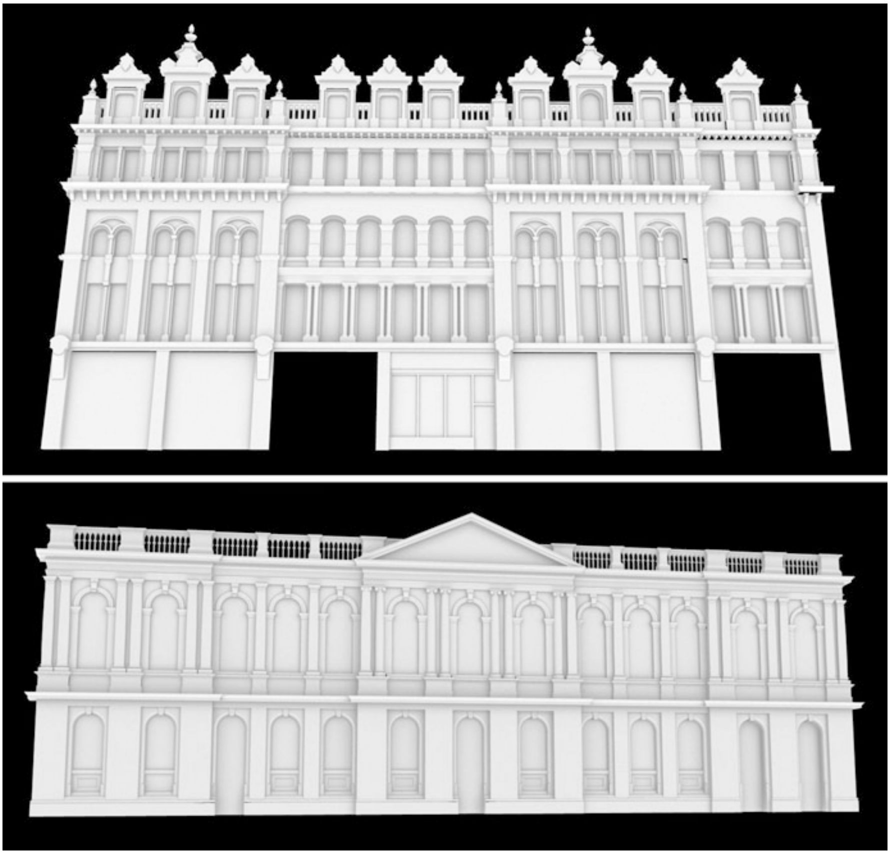

**Fig. 20.8** Rendered images of the ongoing digital reconstruction of two façades (Image source: personal archive of the authors)

### *20.4.6 Virtual Environment in Unity*

Today game engines represent the best solution to create virtual navigable environments. Due to these software packages, it is possible to develop highly detailed immersive and interactive virtual worlds that can be currently found in many games such as GTA V (Rockstar Games 2013) or Skyrim (Bethesda Softworks 2011). For the purpose of this study, selected game engines that allow to create a 3D environment and navigate through it using a first person point of view were considered: Unity, Unreal Engine and Cryengine. Of those, Unity was chosen for its versatility (it is used to develop games for various platforms: PC, consoles and mobile devices) and its friendly user interface. This game engine is already being used in architecture and related disciplines, especially for visualization purposes (Indraprastha and Shinozaki 2009). One of the bigger challenges that was tackled

**Fig. 20.9** Test of textured objects imported into Unity; stone texture material (Image source: personal archive of the authors)

was related to how to correctly import in Unity the geometric objects modelled in another software package. Several import tests, especially focused on scale and geometry, from Rhino and 3DS Max into Unity were performed; these tests have already allowed to define a correct sequence of passages and parameters to correctly import 3D objects in UNITY. In videogames, 3D objects are usually optimized, that is, they present a low number of polygons and a clear and correct geometry. Hence, particular work is been invested in optimizing the 3D elements. Moreover, in videogames, the same objects are usually repeated several times in the virtual environment to save memory and time; however, they can always be customized accordingly. The same approach has been used in the creation of the virtual Grainger Street. As stated above, similar architectural elements were standardized where real-world differences are negligible. Hence, in Unity several prefabs (special objects that act as a template from which is possible to create new object instances in the scene) have been created, one for each repeated architectural element of a façade (windows, pillars, doors). Each instance created from the prefab has been customized accordingly, for example, using slightly different textures to make two stone columns that have the same geometric features look different.

Apart from modelling, 3DS Max was also used for both optimizing the geometry and texturing. Pictures of materials and architectural elements along Grainger Street represent an important source of information and a base to create textures in Photoshop. The picture below shows the basic stone texture created and its application on an architectural 3D element (Fig. 20.9).

The ongoing work on the case study on Grainger Street has presented a series of methodological and technical challenges; the digital reconstruction of the facades of a historical street is a time-consuming work for both the necessity of carefully simplifying the geometry and for the missing portions in the point clouds. Another challenge was the import of models in Unity from a 3D modelling package.

Next phase of the project will go in parallel with the digital reconstruction of Grainger Street and will focus on the collection of people's memories; then the virtual environment in Unity will be completed and populated with interactive elements. People's memories and stories will be collected during several activities: workshops, exhibitions and urban lab.

## 20.5 Conclusions and Future Developments

In this book chapter, a theoretical approach and a tool useful to establish a dialogue between designers and lay people during participatory design activities has been defined. Videogame concepts and a game engine, Unity, have been used to define and create an Architectural Portal of People's Narratives. Experts provide the architectural 3D navigable environment and citizens their memories and stories linked to a specific place. To define the theoretical framework that underlies the Architectural Portal of People's Narratives, it was essential to identify the five main issues that influence the interaction between designers and users in participatory design activities. Serious games provide playful learning experience that can increase people's interest in architecture, urban design and related activities. The literature review covered relevant aspects and connections between participation, 3D models has participatory tools, 3D representation of cities in videogames and the use of serious games as participatory tool. As demonstrated by the literature review, this last area of research, and especially the use of game engines for the creation of 3D navigable and interactive environment, is still under developed. There are many unexplored potentials that should be investigated, especially linked with typical features of videogames such as immersion, interactivity and playfulness.

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# Part VII
# Gamification

# Chapter 21
# How to Use Game Elements to Enhance Learning: Applications of the Theory of Gamified Learning

**Richard N. Landers, Michael B. Armstrong, and Andrew B. Collmus**

**Abstract** The theory of gamified learning (Landers RN, Simul Games 45(6):752–768. doi:10.1177/1046878114563660, 2014) presents a theoretical model in which game elements, drawn from the serious games literature, are used in isolation or in limited combination to gamify existing instructional processes in order to improve learning. Critically, individual game elements must be linked to specific behavioral, motivational, or attitudinal outcomes, which in turn must be linked to learning outcomes, in order for gamification to be effective. Without establishing such links, gamification may appear to be unsuccessful when implementations have in fact succeeded. In this chapter, we expand upon the theory of gamified learning by providing applied examples of each of the nine major categories of game elements and linking those elements theoretically to the behavioral and attitudinal constructs they are best predicted to affect. In short, we explain how to gamify learning in a scientifically supported fashion. We conclude with recommendations for both research and practice of gamification in learning.

**Keywords** Gamification • Gamified • Learning • Motivation • Psychology • Education • Technology • Serious games • Educational technology

## 21.1 Introduction

Gamification, which involves the implementation of game elements in non-game contexts, has become a popular method by which to improve classroom instruction at relatively low cost. Consideration of gamification often comes when learning designers hear about the potential of game thinking to improve education or employee training but realize that the creation or adoption of a stand-alone digital game is typically quite expensive, at least when it is "done right" by carefully matching game design to prespecified learning objectives. Gamification, in contrast, can

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generally be implemented in preexisting instruction to improve learning outcomes without great expense. In fact, the primary advantages to gamification in comparison to the development of serious games are cost and convenience. The key, however, is doing so in such a way that learning gains are realized.

In order to provide some guidance on how to actually obtain increased learning from gamification, Landers (2014) introduced the theory of gamified learning. This theory has two major components: a framework describing categories of game elements that are most likely to improve learning and a theoretical model linking gamification efforts and learning. The framework can be used to identify specific game elements that can be applied in learning contexts, such as game fiction, control, or immersion. The model can be used to support theoretical linkages between such elements and learning via attitudinal and behavioral change. For example, elements might be used to increase learning by first increasing the likelihood that learners will enter a state of flow (Shernoff et al. 2003). Landers and Landers (2014) provided the first test of this theory, linking leaderboards to learning performance through increased time-on-task. In short, the use of leaderboards designed to increase time-on-task can increase the total amount of time that learners spend on a learning project, in turn increasing their performance on the project. Such linkages are the key to realizing the benefits of gamification and to avoid becoming one of the vast number of predicted "gamification failures" that have been warned (Pettey and van der Meulen 2012).

Unfortunately, research in this domain is still quite nascent, so relatively few such links have been established and even fewer empirically supported. Given this, the purpose of this chapter is to provide theoretical support and practical examples for each of the game element categories described in the theory of gamified learning. We will do this by first describing the theory of gamified learning, its game element category framework, and its theoretical process model. Next, we split our presentation by six major psychological theories that lend support to the application of these categories to learning. Within each of these six sections, we first present a summary of the theory alongside a description of current empirical support for it and second present each game element that could take advantage of this theory to realize learning gains, describing empirical research where available. These suggested relationships are summarized in Table 21.1, alongside the theory of gamified learning.

Importantly, the approaches listed here are very likely not the only ways to realize learning gains through gamification. In our review of the literature, we simply found them to be most promising given current research on both gamification and psychology. Thus we present them in the hopes that they will provide guidance to both researchers looking for theories to support specific gamification interventions and also to practitioners looking for those gamification interventions that are most likely to produce gains for their learners. Given this, we conclude this chapter with recommendations for how to best utilize this information in both research and practice, including specific guidance on methodology and statistical testing in both contexts.

**Table 21.1** Game element categories from the theory of gamified learning and theories identified to take advantage of those element categories

| Attribute | Theory | Definition |
|---|---|---|
| Action language | Presence theory | The method and interface by which communication occurs between a player and the game itself |
| Assessment | The testing effect | The method by which accomplishment and game progress are tracked |
| Conflict/challenge | Goal-setting theory | The problems faced by players, including both the nature and difficulty of those problems |
| Control | Self-determination theory | The degree to which players are able to alter the game and the degree to which the game alters itself in response |
| Environment | Presence theory | The representation of the physical surroundings of the player |
| Game fiction | The narrative hypothesis | The fictional game world and story |
| Human interaction | Social constructivism | The degree to which players interact with other players in both space and time |
| Immersion | Presence theory | The affective and perceptual experience of a game |
| Rules/goals | Goal-setting theory | Clearly defined rules, goals, and information on progress toward those goals, provided to the player |

Note: Categories and definitions are taken verbatim from Landers (2014)

## 21.2 The Theory of Gamified Learning

Broadly, the theory of gamified learning (1) defines gamification in terms of learning, linking the research on game elements from both the serious games and gamification literatures, (2) presents a theoretical framework of game elements likely to improve learning outcomes, and (3) presents a general model of the psychological processes by which gamification is likely to improve learning outcomes. We describe each of these aspects of the theory in turn.

Landers (2014) defines *gamification of learning* as “the use of game elements, including action language, assessment, conflict/challenge, control, environment, game fiction, human interaction, immersion, and rules/goals, to facilitate learning and related outcomes” (p. 757). This list of nine game element categories, which also appears in Table 21.1, is not exhaustive or comprehensive; instead, it was developed as a list of those elements most likely to be usable to improve learning. This was based upon prior research conducted by Bedwell et al. (2012) in turn based upon work by Wilson et al. (2009). Specifically, across these two studies, these researchers developed a list of ways that serious/learning games are commonly manipulated in order to increase learning according to both game players and developers, then refining this list to a more parsimonious set of categorical labels, in order to minimize non-meaningful overlap between them. If any game elements can be manipulated to improve learning, these are likely to be those elements. Given this, Landers described how these elements could be applied in isolation, outside the context of a game, to gamify learning. In this sense, serious games and gamified learning both utilize the same game element toolkit; they simply differ in how those elements are applied.

The importance of parsimony in this domain cannot be overstated. The serious games literature has long suffered from a high degree of construct overlap, with multiple studies examining the same underlying game element but giving it different labels. Instead of continuing to waste research effort by maintaining independent research streams, Bedwell et al. (2012) suggested that there are underlying attribute categories of games that vary systematically, and that it is these categories that are driving learning differences rather than the superficial differences sometimes suggested in the literature. Attempting to theoretically define gamification makes these divisions more obvious; although Wilson et al.'s (2009) "fantasy" and "mystery" game elements certainly are operationalized differently, they are unlikely to lead to dramatically different outcomes. Instead, these dimensions were empirically collapsed to a single "game fiction" dimension that unites the literatures on various types of fiction. Such models are ultimately more useful when developing and identifying empirical support in this domain.

Landers (2014) was the first to provide a list of examples of gamification based upon Bedwell et al.'s (2012) parsimonious list of game attribute categories, and these categories and their definitions appear in Table 21.1. Importantly, game elements within each of these categories can be applied in isolation, which is what distinguishes gamification from the development of a serious game. For example, assessment can be implemented independently as a gamified learning design, without any other game elements. Importantly, each game element can be supported with different psychological theories or aspects of those theories. For example, as will be described later, rules/goals are most likely to change learner behavior given the tenets of goal-setting theory (Locke and Latham 2013) whereas game fiction is most likely to change learner behavior given the ideas supported by the narrative hypothesis (Graesser et al. 1980a).

The particular way to go about this is also described by the theory of gamified learning (Landers 2014). Specifically, gamification is hypothesized to influence learning through one of two (or both) theoretical paths. In both cases, gamification influences an intermediary learner behavior or attitude but after that, the effect diverges. Some types of gamification influence learning outcomes because this targeted behavior/attitude itself influences learning. In these cases, the targeted behavior/attitude is called a *mediator*. This relationship is depicted in Fig. 21.1. Other types influence learning outcomes because this behavior/attitude changes how effective the existing instructional content is. In these cases, the targeted behavior/attitude is called a *moderator*. This relationship is depicted in Fig. 21.2. Critically, the specific path to learning from gamification must be modeled accurately, as a moderator, mediator, or both, for researchers to truly understand what a particular gamification intervention does and how.

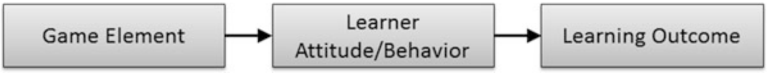


**Fig. 21.1** Causal path from a game element to learning outcomes through mediational learner attitudes/behaviors, as proposed by the theory of gamified learning (Adapted from Landers 2014)

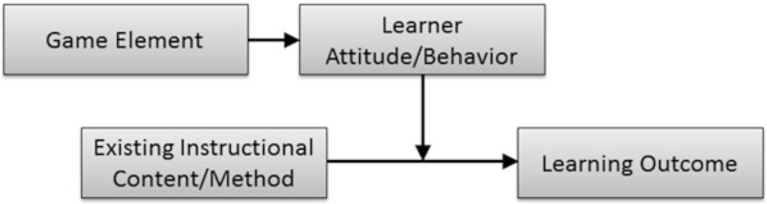


**Fig. 21.2** Causal path from a game element to learning outcomes through moderating learner attitudes/behaviors, as proposed by the theory of gamified learning (Adapted from Landers 2014)

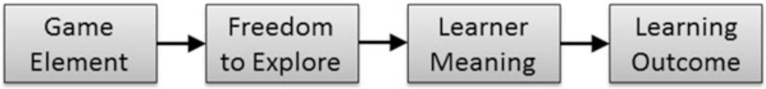


**Fig. 21.3** Nicholson's (2015) *meaningful gamification* via play expressed in terms of the theory of gamified learning

In the first explicit empirical test of this model, Landers and Landers (2014) provides an example of the first type. Specifically, the use of leaderboards (themselves a combination of rules/goals, conflict/challenge, and assessment) influenced the amount of time students put into a course project. This variable, called time-on-task, was thus a target learner behavior. Prior research also suggests that time-on-task is itself critical to learning (Brown 2001). Thus, time-on-task was hypothesized and tested as a mediator in the relationship between leaderboards and learning, in the context of a learning activity.

Many researchers leave the specific nature of this relationship empirically untested, which we believe is harmful to the development of this research literature. For example, Nicholson (2015) proposes a concept called *meaningful gamification*, which suggests that for gamification to be impactful, it should contain six components: play, exposition, choice, information, engagement, and reflection. Thus, Nicholson is implicitly suggesting two mediators in series between gamification and learning. First, gamification must facilitate the freedom to explore (i.e., play), create stories for learners (i.e., exposition), etc., according to this six-dimension model. Second, once these learning states have been created, the learner must experience from them some kind of *meaning*, presumably a psychological state. Third, once the learner has experienced meaning, this experience of meaning should lead to learning outcomes. A model summarizing this relationship for *play* is shown in Fig. 21.3. These are all testable ideas, yet empirical support for them is not available. The theory of gamified learning provides a model under which to provide such support.

In summary, the theory of gamified learning provides a framework of game element categories that researchers and practitioners can focus upon with the goal of improving learning through gamification. These categories are not exhaustive lists of game elements, but rather describe groups of game elements that are likely to produce similar effects for similar reasons. The theory also provides a process model describing the linkages between such game elements and learning outcomes through intermediary psychological processes. In the sections that follow, we will describe several psychological theories that we find provide the most promising intermediary processes to fulfill this role.

## 21.3 Goal-Setting Theory and Self-Regulation

Game elements can influence learning through the mediational effects of self-regulation, which refers to the continual process of comparing one's goals to one's own performance and adjusting their behaviors as necessary to minimize the gap (Locke 1968). One prominent application area of self-regulation is described by goal-setting theory (GST), a motivational theory explaining how goals can be created in order to maximize performance (Locke and Latham 2013). GST provides many specific mechanisms for this; for example, the motivational affordances of goal setting are maximized when there is feedback on one's progress toward a goal (Ambrose and Kulik 1999). Setting goals and striving for their achievement forces one to engage in self-regulatory processes. However, not all goals are equally effective. A common mnemonic summarizing the recommendations from goal-setting research is that to maximize outcomes, goals should be SMART: specific, measurable, attainable, realistic, and time bound (Doran 1981). SMART goals have been applied to increase learning quite effectively, and numerous guides are available explaining how to do so (e.g., O'Neill and Conzemius 2006).

The use of GST to increase motivation and performance in a wide variety of contexts is very well supported by decades of empirical evidence. There is even an abundance of meta-analytic evidence, the most comprehensive sort of scientific evaluation currently available (for a review of this, see Locke and Latham 2002). As a result, there is currently a scientific consensus that goal-setting interventions generally influence the behaviors they target.

In the learning context, there is one subtle effect not proposed in core GST worth discussing in greater detail: performance goals commonly decrease learning (Seijts and Latham 2005). The most common reason provided for this is that goal-setting interventions encourage the "wrong" behaviors. Trying to get a high score on a test, for example, encourages the learner to focus on and plan for "getting a high score" instead of learning. In such a situation, spending time planning how to cheat on the test might be seen as a valid way to "get a high score" but is in fact counterproductive to learning. Furthermore, to the extent that the learner does not know how to get a high score (i.e., by learning), time will be wasted, and the goal will not result in the desired outcome. To avoid this problem, learning goals are best set when increased learning is the desired outcome (e.g., setting a goal of “I will learn three different strategies to solve this problem” instead of a performance goal of “I will solve this problem in the next hour”; Winters and Latham 1996). While researching performance versus learning goals, it was observed that individuals who set learning goals tended to report higher levels of satisfaction. Specifically, Latham and Brown (2006) found that, among MBA students, learning goals lead to the highest satisfaction ratings among various goal conditions.

### *21.3.1 Applying Goal-Setting Theory via Rules/Goals Game Elements*

As previously mentioned, the motivational affordances of goal-setting theory are maximized when there is feedback on progress toward the goal. This naturally coincides with the rules/goals game element and is potentially one of the easier elements to capitalize on in gamified learning. When learners receive feedback on their progress toward any goal, they are able to better understand the problem that goal represents and refocus their learning efforts as needed. Similarly, rules can help illuminate a learning concept or theoretical boundary condition.

Garris et al. (2002) specify that rules and goals should be clear in order to facilitate learning. This is likely necessary but not sufficient for learning. Clearly stated rules and goals can be followed and acted upon, but if they are boring, learners will not be motivated to engage with those rules or learning goals. Garris and colleagues further note that goals must also be flexible enough to allow for a range of actions. It is in this flexibility that players’ styles and strategies come through. If rules are too constrictive, then the following of rules is no longer fun because it does not allow for the expression of style and strategy.

In the context of the theory of gamified learning, the importance of rules/goals is that set rules/goals successfully influence a particular targeted attitude or behavior. Rules/goals game elements are generally broad enough that this target could be any learning-relevant attitude or behavior. For example, consider an instructor that has noticed students are no longer attending a lecture-based class. A goal could be set for the class to attain at least a 90% attendance rate every day, with a small bonus point award at the end for the entire class for attaining this goal. The specific nature and value of the bonus point award is irrelevant; extant research on GST suggests that the precise value of rewards is less critical than their mere existence. Their primary role is instead to signify accomplishment of the goal, as a point of pride. In this case, the target behavior is in fact learning whereas the intermediary learner behavior targeted by gamification is attendance, an example of the mediational path in the theory of gamified learning. Thus, in this example, rules/goals are hypothesized to influence attendance, which is hypothesized to influence learning.

Importantly, such rules/goals should not be targeted at learning itself. As noted earlier, performance goals often interfere with true learning goals. If the instructor described above had instead set a goal for the class to "get a high score on the next test," such a directive is likely to interfere with learning. Gamification must *feel* optional such that learners perceive that they are choosing to engage with the rules/goals willingly. This was a key aspect of Landers and Landers' (2014) leaderboard intervention; the leaderboard created goals that were likely to be associated with learning but were not themselves learning goals, such as being among the first in the class to work on their projects, or among the first to figure out how to upload pictures. As soon as rules/goals are *required*, they are no longer gamification – they become part of learning/academic performance.

### *21.3.2 Applying Goal-Setting Theory via Conflict/Challenge Game Elements*

Conflict/challenge is a powerful game element in learning contexts (Malone 1981). Challenge coincides with the "difficult" and "attainable" aspects of SMART goals. Specifically, people need to feel challenged by goals, but not overwhelmingly so, in order to find them motivating. If a goal is too easy, it will be perceived as trivial and will not produce a sense of satisfaction for accomplishing it, yet if a goal is too difficult, it will be perceived as impossible, unfair, and demotivating. Thus, a balance must be achieved between the two extremes in order to maximize the impact of goals. This is particularly difficult in contexts where learner skill and preparedness varies greatly; that which is excessively difficult for one learner may be simple for another.

Conflict/challenge can be implemented into a learning context by carefully considering the difficulty of specific tasks. For example, a common group discussion activity in the classroom involves breaking into small groups and coming to consensus within each group on some issue related to class material. Afterward, each group shares its result. However, the only goals in this context are those self-imposed by the learners. One group may be filled with high achievers, hoping to impress the instructor by developing as perfect a response as possible. Another group may be filled with low achievers, who just fabricate an answer on the spot when asked at the end. By creating a specific, difficult goal for each group to pursue, one takes advantage of goal-setting theory. It communicates to each group that they are capable of and expected to come up with an answer to a particular problem, which increases the self-efficacy of group members and targets their effort. For example, if the goal of group discussion in a government class was originally to determine, in hindsight, what the "best" course of action was for each country in Europe at the dawn of World War II, conflict/challenge might be introduced by assigning each member of the group to determine the best course of action for his/her assigned country and then to task the group with coming to a single consensus judgment. Because the best action "for Europe" and the best actions for individual countries are likely to be different, each member of the group discussion has now been personally challenged. This is likely to increase group discussion engagement (a mediator, in terms of the theory of gamified learning) and therefore learning outcomes.

## 21.4 The Testing Effect

The theory of test-enhanced learning, commonly known as the testing effect (Roediger and Karpicke 2006), provides insight into how game elements can affect learning outcomes by influencing cognition. The testing effect is a phenomenon in which learners who are tested on learning material retain that material better than if they had not been tested, even without receiving feedback on their performance (Roediger and Karpicke 2006). Testing triggers learners to retrieve previously learned information. By retrieving that information, they are in essence practicing remembering, and thus overall retention of the information is improved, strengthening future attempts at retrieving that information.

Importantly, testing provides benefits in long-term retention beyond that of studying. Giving learners the opportunity to either study a lot with no practice tests or to study a little and take several practice tests instead of studying can result in differences in learning recall and retention. Roediger and Karpicke (2006) found that recall of material one week after being randomly assigned to study or testing sessions was better for those completing tests. Learners who were repeatedly tested forgot less information over time than learners subjected to repeated studying only. There are many possible mechanisms by which this testing effect might occur, but it is likely due to a number of memory-related mechanisms (see Rowland 2014 for a discussion on the plausible mechanisms and their supporting evidence). For example, retrieval practice may generate additional cognitive routes to retrieval through cues presented at each retrieval.

Empirical evidence strongly suggests that the testing effect can substantially improve information recall. According to a meta-analysis conducted by Rowland (2014), the testing effect causes an improvement in recall by a half standard deviation over study-only conditions. The testing effect is much larger for recall assessments (e.g., short answer, fill in the blank) than for recognition assessments (e.g., multiple choice; Rowland 2014), which show the opposite pattern. Specifically, studying makes multiple choice easier and recall harder, whereas testing makes recall easier but multiple choice harder. Recall is more in alignment with learning objectives than recognition, as it is a better indicator of learning. For example, most instructors would prefer their learners are able to spontaneously remember and describe details about the material than to recognize patterns on multiple-choice tests. The testing effect also demonstrates a clear advantage for long-term recall, which is the ultimate goal of instruction (i.e., rather than short-term recall), over studying.

Further, the testing effect improves learning even when feedback is not given (i.e., when not informing the learner which of their answers were correct), although providing feedback to the learner improves learning further (Roediger and Butler 2011; Rowland 2014). Learners must correctly recall the information at initial tests in order to successfully recall that information at final tests. Providing feedback in initial testing allows learners to correct errors in memory before final testing (Roediger and Butler 2011).

Given this body of research, the key to eliciting the testing effect is providing opportunities for learners to complete learning-related assessments or exercises as they progress through learning materials. Receipt of feedback on their performance as they complete these assessments is not necessary to elicit the effect but is further beneficial to learning.

### 21.4.1 Applying the Testing Effect via Assessment Game Elements

If testing positively impacts learning elements, learning should be gamified in a way such that game elements impact and prompt that cognition. The most appropriate element for prompting testing behavior is assessment. Assessment is defined as the method by which accomplishment and game progress are tracked (see Table 21.1). Examples of assessment found within games include points, badges, and leaderboards. Often, assessment of game progress and accomplishment comes in the form of rewards (e.g., the player reaches the end of a level and is given a score or summary of performance or obtains a badge marking the accomplishment). In a learning context utilizing the testing effect, rewards might be distributed to learners for participation in practice tests in order to encourage practice recalling information. For example, a badge might be awarded to the learner for completing a quiz on a particular subject (Landers and Callan 2011). Although these forms of assessment can be motivating (Mekler et al. 2013), not all people react the same to these elements of assessment. Some users may find little value in the gamification if the assessment lacks an appropriate context (Montola et al. 2009). For example, some learners may find the goal of earning points to be subjectively unrewarding if the points do not translate to some real-world reward. Others may find that accumulating points and badges is so engaging that it promotes friendly competition with other users (Montola et al. 2009). Assessment elements need meaningful value for the learners in order to promote additional testing behavior. Learners will not pursue rewards like badges or leaderboard positions if they do not value what those rewards represent (Landers et al. 2015).

To maximize the value of assessment, McDaniel and Fanfarelli (2016) explained how digital badges can be used to promote completion behavior, such as taking additional tests. Badges can direct behavior through goal setting, providing feedback, and debriefing. Badges can provide a goal to direct future learning behavior (e.g., win this badge for completing three bonus quizzes). Badges can also provide feedback while learning (e.g., taking a practice test and receiving a badge for receiving a certain score), which then directs future behavior (e.g., persisting with practice tests to win more badges). Badges can prompt reflection as a form of debriefing (e.g., reflecting about test performance and effort after completing a learning session in relation to what badges were earned during the session), which can then impact future testing behavior. Each of these attitudes and behaviors (i.e., completing extra quizzes, reading extra feedback, and reflecting) are thus mediational behaviors as described by the theory of gamified learning.

Landers and Callan (2011) provide a practical example for utilizing an assessment element to promote practice testing. The authors awarded badges to learners in order to increase participation in taking voluntary quizzes in a college course. Students were awarded badges for completing optional online quizzes over course content. Students' grades in the course were neither dependent on quiz participation nor quiz performance, so participation in the quizzes was entirely voluntary. Student feedback indicated that students were motivated to complete the quizzes and earn the badges, which in turn provided more opportunities for testing and practice recalling content from the course. The gamification implemented in the course provided meaningful context for the badges to the learners in multiple ways. First, some students perceived the badges as goals, with goal accomplishment serving as a source of feedback to the learners' competence (Antin and Churchill 2011). Second, the gamification was implemented within a university social media platform, allowing students to view each other's badges and provide an environment for competition and comparison, another source of feedback.

## 21.5 Presence Theory

Game elements can be used to impact learning by creating a subjective state of presence within a learning environment. Presence is "the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer and Singer 1998, p. 225). A state of presence is likely to be experienced, for example, while engaged in a virtual reality experience. A person might experience a virtual reality or virtual environment based on an ancient city and culture. The person might navigate a simulation of the city through immersive technology in order to learn about an ancient people or their culture. Even though the person is at home in the present day, the person may feel a sense of presence in the virtual reality – a sense or feeling, even if only momentarily, of truly being in that ancient city. Although presence is easier to create in an environment as immersive as virtual reality, it is not required. Presence may be induced by any form of media (e.g., a website).

At a minimum, fostering a sense of presence requires creating both involvement and immersion. Involvement is "the psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events" (Witmer and Singer 1998, p. 227).

Immersion, as defined by the presence literature, is “the psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences” (Witmer and Singer 1998, p. 227). In short, presence depends on a person’s attention and focus shifting from the physical environment to the virtual environment. In the context of learning, the goal would be to shift a learner’s attention from his or her physical environment to the subjective experience of the learning environment. A learner might be sitting in a classroom, but that does not mean that this person is engaged with the learning environment. The learning environment should capture the attention of the learner while also allowing the learner to feel included in the environment, capable of interacting with it. By immersing learners in the learning environment, learning-irrelevant distractions can be dismissed, allowing more focus on the learning content.

A related topic to presence is the state of flow (Nakamura and Csikszentmihalyi 2002). Flow is similar to the state of presence, except that, in addition to requiring concentration, flow requires interest and enjoyment (Shernoff et al. 2003). From a learning perspective, however, the necessary elements to create a state of both flow and presence are quite similar.

In research on virtual reality and learning, characteristics of virtual reality are likely to affect learning through perceptions of presence (Salzman et al. 1999; Lee et al. 2010). Different features of virtual reality, such as visual, auditory, or haptic stimuli, are theorized to induce a sense of presence by increasing perceived fidelity of the virtual environment. The immediacy of interacting with the virtual reality (i.e., how quickly the virtual environment reacts to the user’s actions) also affects presence. If interaction with the virtual environment is smoother and more immediate, presence will increase. The presence may affect learning through a higher quantity of higher-quality information (i.e., visualization, audio, and haptics give more context to the information presented). Through interaction with the virtual environment, users can engage in active learning. Lee et al. (2010) tested this path using structural equation modeling and found a significant positive relationship between presence and learning outcomes. However, the measure for presence was a single item developed by the authors; thus, it is unclear how reliable this measure was and therefore how trustworthy the results are. Although cognitive and affective learning outcomes were included in the study (Kraiger et al. 1993), much of the effect of presence on learning seems to be due to the affective outcomes (e.g., satisfaction with learning). It is difficult to determine how much of a role presence may play in learning in non-virtual reality learning contexts. Lee et al. (2010) found that a desktop computer program is enough to induce a state of presence and affect learning, but these results should be interpreted with caution, as other factors may have played a larger role in learning (e.g., learner control or reflective thinking).

### *21.5.1 Applying Presence Theory via Action Language Game Elements*

Action language can be used to improve the sense of presence in order to affect learning; thus, presence is itself the mediator when this is applied to the theory of gamified learning. Action language represents how a player communicates with the game, or how a learner might communicate with the learning environment or system, and this language can induce a state of presence. For example, in playing a video game, the action language might include pressing buttons on a video game controller. Action language in an online learning management system might be using a computer keyboard and mouse. In playing games, the control interface or action language plays a role in affecting the state of presence (Shafer et al. 2014). To induce presence, action language should be easy to use and useful, which has been supported by research in virtual reality (Lee et al. 2010). When using game elements like action language to induce presence, those elements will also need to be easy to use and perceived as useful by the learner. When implementing action language in order to induce a state or presence in the learning environment, it is suggested to use an action language with which learners are already familiar. Different forms of action language include computer mouse and keyboard; smartphones, tablets, or other touchscreen computers; and video game controller (e.g., for PlayStation, Xbox, Wii, etc.).

Different action languages have different features which may be perceived differently by users depending upon their familiarity with each interface. For example, a mouse is an intuitive way to navigate a computer, but keyboard shortcuts might be more efficient. Video game controllers are generally more ergonomic than standard keyboards, but their application is generally more specific (i.e., controllers are used primarily for games whereas a computer keyboard can be useful for typing, programming, controlling a game, and more). Gerling et al. (2011) compared two action languages on their impact on player experience in a commercial video game. Players reported if they typically played PC games or console games and were assigned to play either the version with which they were comfortable or with the action language they did not typically use. Differences in presence and immersion measures were small, but a significant, moderate difference in "absorption," or engagement, was found favoring the unfamiliar action language. It is possible that using unfamiliar action language, which is more challenging (Gerling et al. 2011), prompts players to be more engaged with the game or task at hand. Players must be more alert when using unfamiliar controls in order to avoid errors. Although this may increase absorption or engagement, this stimulation does not necessarily support immersion in the experience. This conclusion supports the theory that perceived ease of use and perceived usefulness of an action language supports the state of presence.

More immersive action languages than standard computer interfaces are possible in learning. For example, medical procedure simulations use realistic tools as controls within a virtual environment. (Wilson et al. 1997; Aggarwal et al. 2004).

Trainees can practice making maneuvers typical of a procedure using a computer screen and standard medical instruments (e.g., laparoscopic instruments). By creating a virtual experience similar to a real-life medical procedure, trainees may feel presence in the virtual medical procedure without consequences for technical errors. In addition to specialized action languages like medical instruments, new technology also provides outlets for more immersive experiences. Smartphones, tablets, and other touchscreen computers are becoming more common, making this action language an increasingly viable option in learning settings. The interactivity of a touchscreen in combination with the dynamic nature of a computer screen can create new engaging learning experiences that were previously not possible. Additionally, video game play is rising globally (Lofgren 2015), making video game controllers another viable action language as well.

One important caveat with the implementation of action languages is that this may require training for learners to understand how to use those action languages, which could interfere with learning. Specifically, when learners can process information with little or no conscious awareness, such as how to use a given action language, overall cognitive load is reduced, freeing cognitive resources for learning the content rather than a learning management system, a state called automaticity (Feldon 2007). If a learner is familiar with an action language already, that learner will require less practice and cognitive resources to become proficient enough at the action language to take advantage of its interface with a learning management system. Care should be taken to either implement action languages that are already familiar to learners or to ensure that they are trained such that action language use becomes automatic before learning with it.

### *21.5.2 Applying Presence Theory via Immersion Game Elements*

The second game element that can be used to affect presence is immersion. It is positioned similarly in the theory of gamified learning – immersion game elements can be used to create presence (the mediator), in order to affect learning. Immersion represents the "perceptual and affective relationship of the player with the game fiction," which is embodied through players and their representation (e.g., pieces in a board game, avatars or characters in a digital setting), sensory stimuli (i.e., visual, audio, haptic), and the sense of safety (Bedwell et al. 2012, p. 742). It is distinct from the psychological state of immersion described earlier. One way of conceptualizing immersion is in terms of the acceptance, even temporarily, of the player of the alternate reality presented. If game attributes like player representation, sensory stimuli, and sense of safety contribute to an immersive experience, the player will be more likely to suspend his or her disbelief in the reality presented by the game. Similarly, if these attributes contribute to an immersive experience in a learning environment, they should contribute to presence and thus impact learning.

Each type of immersive game element can be applied in order to facilitate presence in learning. As the representation of players becomes more realistic and relevant (i.e., versus abstract representations found in many board games like Sorry or Monopoly), presence should improve. In a video game or virtual environment, learners should find the content more relevant as they take on a realistic role in the environment rather than an irrelevant or uninvolved role. As sensory stimuli increase in fidelity through visual, audio, or haptic enhancements, presence should improve. This might involve the use of graphics or relevant audio, which would be easy to implement in a learning context. A simple example might be to include a video in a lecture in order to demonstrate a concept or procedure. Increasing the sense of learner safety might also improve presence. Dissociating actions from consequences (i.e., acting without fear of repercussions) removes concerns for the real world, allowing learner attention to focus on the virtual learning environment. This is evident in the example of medical procedure simulations, where trainees can practice skills where errors do not cause harm to patients. Some consider this to be the crux of video games; players can try and retry continuously when they fail at a task. Although these game attributes might contribute to a sense of presence, they may not necessarily improve learning. Research on fidelity shows that higher fidelity simulations are sometimes distracting and detract from learning. Gamified learning environments should be designed in such a way as to utilize a high quantity of high-quality information to improve fidelity only as much as necessary to meet learning objectives, and we recommend consulting the human-computer interaction research literature for recommendations on this.

### *21.5.3 Applying Presence Theory via Environment Game Elements*

The third element that can be used to affect presence is environment. Environment represents the location of the player within a game (e.g., playing a physical game of tag outside in a field or playing a video game set in a fictional galaxy). This element influences the rules and expectations of the game and may be real or fantasy (Bedwell et al. 2012). Different environments may impact presence in various ways. Depending on the learning context, some environments may be more relevant than others. Learning about deep-sea oil drilling using a virtual oil rig environment might be more relevant to learning material than the same information in a classroom, improving the sense of presence in the learning environment. Environments might also impact presence differently depending on learner's preferences for different environments. Learners may prefer to learn technical skills on a job site rather than in a classroom, whereas others may prefer classroom learning. Returning to the example of medical trainees, some trainees may prefer to learn new procedures by watching a video in a classroom, while other trainees may prefer to learn through trial and error in practicing a new procedure.

If learner preferences for environment are not matched with the learning environment, the learners may be distracted by their environment, decreasing their sense of presence and overall learning. For example, an instructional designer might use technology like virtual reality or video games to create a digital environment to enhance learning. If the objective of learning is to learn about an ancient culture, designing a virtual environment based on an ancient city might be an appropriate environment for enhancing learning. However, if the objective of learning is to teach algebra, a virtual environment of an ancient city might be interesting but distracting from the learning objectives. Instructional designers should build different environments using technology to suit the needs of different learning situations and learner preferences.

## 21.6 Self-Determination Theory

Self-determination theory suggests that motivation is rooted in the fulfillment of three basic psychological needs: autonomy, competence, and relatedness (Ryan and Deci 2000). As people experience greater control or autonomy over their own choices and actions, as they feel more competent at what they are doing, and as they feel more socially connected to other people, their motivation to choose or act approaches intrinsic motivation. A person is intrinsically motivated when they are doing something for fun, for its own sake, because it is interesting, satisfying, or enjoyable (Deci and Ryan 2000; Ryan and Deci 2000). Intrinsic motivation is tied to a variety of positive outcomes, one of which is learning (Deci et al. 1991; Ryan and Deci 2000). Of particular interest to intrinsically motivating learning in the context of gamification is the need for autonomy. As learners have more freedom in how and what they learn, they become more motivated to learn. Motivation to learn plays a key role in achieving a variety of learning outcomes (Colquitt et al. 2000). Thus, instructors should attempt to enhance learners' motivation to learn in order to improve overall learning outcomes. Although extrinsic motivators such as rewards and deadlines can be motivating, research on self-determination theory suggests that more intrinsic sources of motivation will lead to greater learning outcomes and supporting autonomy is one way to do this (Deci et al. 1991). Thus, game elements should be used to provide support for the autonomy of learners in order to enhance motivation to learn and subsequently overall learning.

In practice, providing autonomy support for learners might be best exemplified through the concept of learner control. Learner control refers to the extent to which a learner can affect his or her learning experience by altering features in the learning environment (Friend and Cole 1990; Kraiger and Jerden 2007). There are a variety of features in learning environments that a learner might adjust in order to alter his or her learning experience (Kraiger and Jerden 2007; Karim and Behrend 2014; Landers and Reddock in press). For example, a learner might adjust the pace of learning in a web-based instructional setting. If the learner already knows about a topic, that learner may choose to spend less time on that topic. Alternatively, if the learner needs more time to fully comprehend the concepts presented, that learner may choose to spend more time reviewing the content. Learners might also be given control over other aspects, such as the time and location of instruction (Karim and Behrend 2014). A learner may choose when and where to learn, according to what best fits his or her schedule.

Meta-analytic evidence for the effects of learner control on learning outcomes is mixed (Kraiger and Jerden 2007; Landers and Reddock in press). Giving learners certain types of control over their learning environment is motivating, but this does not necessarily lead to larger learning gains. Types of control vary in their effectiveness at improving learning outcomes (Landers and Reddock in press). For example, giving learners control over the sequencing of learning material has a small positive effect on learner satisfaction with the instruction, but has a minimal effect on knowledge learning. In general, sequence control has a positive effect on learning, whereas other types of learner control have neutral or negative effects for different outcomes. However, it is possible that the relationship between learner control and learning outcomes is moderated by characteristics of the instruction or characteristics of the learner, such as the learner's preference for control (Kraiger and Jerden 2007). For example, if a learner is given control over learning, but would rather have an instructor guide the learner through the content, learner control might not positively impact learning. Although learner control should theoretically improve motivation to learn by satisfying a need for autonomy (Ryan and Deci 2000), this need has not been hypothesized in current models of learner control (Kraiger and Jerden 2007) or tested. Thus, it is possible that the learner control and learning relationship is mediated by motivation to learn, consistent with the theory of gamified learning (Landers 2014).

### *21.6.1 Applying Self-Determination Theory via Control Game Elements*

Control as a game element is conceptually similar to learner control: "the degree to which players are able to alter the game, and the degree to which the game alters itself in response" (Landers 2014, p. 756). By giving learners control, their need for autonomy is satisfied, increasing their intrinsic motivation to learn, which should lead to improved learning outcomes (Colquitt et al. 2000). Although learners may be motivated by having the freedom to set the pace of learning or the freedom to decide on the sequence of content, the effects of these forms of control are overall small for learning. Elements of control may be more useful when combined with other game elements.

A learner's need for autonomy might also be satisfied by combining elements of control with other elements, such as immersion or human interaction. For example, within a computer-based instructional system or learning management system, learners might be given control over aesthetic features, a component of immersion (i.e., sensory stimuli or representation, Bedwell et al. 2012). If a learner were given control over the appearance of an avatar or of the software application itself, his or her need for autonomy might be satisfied without relegating total control over learning content to the learner. As another example, if the learning management system has a social sharing feature, learners might be given autonomy in how much content they share with other users. If a learner was excited about completing a particular course module, that learner might want to share his or her achievement with others. Additionally, learners are not proficient at deciding what content needs to be learned (DeRouin et al. 2005; Brown and Ford 2002), so by giving learners freedom in other ways, instructors can guide learning while maintaining an intrinsic motivation to learn.

There are many ways to gamify learning with control. Based upon their meta-analysis, Landers and Reddock (in press) provided nine methods in the context of web-based instruction, allowing learners to skip material they already know, to add material for extra study, to change the order of learning material that they experience, to add or skip knowledge/skill assessments, to receive guidance and determine a course of action in response, to change the stylistic details of the learning environment, and to control when and where they complete their learning. However, because effects vary by outcome, it is recommended to choose control techniques aligned well with learning goals. Outside of web-based instruction, where the trajectory of a course can change from session to session, there are more options, some of which are quite simple. For example, if an instructor was trying to choose between two supplementary videos for class with similar content, one way to provide control to students is to ask them to vote on which video they would rather see. Such control should improve learner motivation, which should in turn strengthen the effectiveness of the instructor's existing instructional approach (i.e., an example of the moderating path in the theory of gamified learning).

## 21.7 The Narrative Hypothesis

The narrative hypothesis provides insight into how a story or narrative element, which is common to many games, can impact learning outcomes. The narrative hypothesis suggests that when learning from text, the information from a narrative genre text is better learned and retained than the information from an expository or descriptive text (Graesser et al. 1980a; Adams et al. 2012). For example, the narrative hypothesis suggests that when learning historical information about a world leader, that information would be better learned when presented as a story rather than as a series of facts without a narrative. Narrative texts are thought to be more memorable than expository texts for several reasons, which forms the basis for the narrative hypothesis. Within narratives, events are more concrete and usually have a causal ordering. This is in contrast to expository texts, which are generally more abstract, providing facts and information which may or may not be related to other facts or information presented in the same passage. Also, narratives might be better understood or better liked by learners (Cunningham and Gall 1990), which may be another way of explaining its effects on learning retention over expository texts (Graesser et al. 1980b).

The narrative hypothesis has received much empirical support in laboratory studies (Graesser et al. 1980a; Tun 1989; Best et al. 2008), but has received less support in actual educational contexts (Cunningham and Gall 1990). Graesser and colleagues (1980a) assessed learner recall of information presented in various text passages across text genres. Learners recalled more information from narrative passages than expository passages, regardless of how familiar the learners were with the content of the passages presented. This finding suggests that when learning from text, learners will learn better from narratives than non-narratives. In a later experiment, Graesser and colleagues found that information presented in narrative texts was also better retained than information presented in expository passages. In a separate study, (Graesser et al. 1980b) found that of these same passages, the narrative passages were read significantly faster than the expository passages. Narrative passages are more easily understood and processed than expository passages, which makes them easier to read. Although these findings are optimistic for the use of narrative in learning, Graesser and colleagues' (1980a; b) findings were conducted in a laboratory setting, which limits their generalizability. The information presented to learners was recalled and retained better in narrative passages than in expository passages, but none of the information presented was particularly relevant to the learners. It is possible that expository passages might be just as well recalled and retained should a learner be sufficiently motivated to learn the content. Further, the passages did not contain equivalent information across genres. The narrative genres included stories such as "Noah's Ark" and "Snow White," whereas expository passages were about topics including earthquakes, emotions, energy, and animals (Graesser et al. 1980a). The nature of the content of the passage could possibly impact how successful that content is recalled and retained. Narratives should be compared to expository texts, holding informational content constant for a more accurate estimate of the effect of text genre on recall.

Results from field research are more limited. For example, Cunningham and Gall (1990) compared expository texts to narrative texts in classrooms with middle and high school students using the same instructional content across genres. Although narratives were more satisfying to students overall, there were no differences in learning across text genres. This does not provide strong support for the narrative hypothesis in terms of improving cognitive outcomes outside of a laboratory setting, but more research is needed. Regardless, there appears to be broad value for the use of narrative in learning overall. Norris et al. (2005) identified 20 of 23 experimental studies conducted comparing narrative to expository texts that found a positive effect of narrative on learning outcomes.

### 21.7.1 Applying the Narrative Hypothesis via Game Fiction Game Elements

Within the taxonomy presented in this text, narrative is considered a type of game fiction (Landers 2014). Game fiction describes the nature of both the game world and the story, each of which may include elements of fantasy (Bedwell et al. 2012; Garris et al. 2002). For example, a game would employ a fantasy game fiction when using images of fictional worlds, wizards, and dragons to convey game context to the player (i.e., the game world) or when demonstrating that the player is a warrior on a mission to defeat a dragon in order to save a kingdom (i.e., the story). The narrative hypothesis suggests that the part of game fiction involving story elements will be useful for impacting learning.

The use of game fiction may impact learning outcomes directly or indirectly. Cordova and Lepper (1996) used game fiction to teach math skills to elementary school students. The authors found that learners reacted more positively (i.e., were more satisfied and experienced more enjoyment) and learned significantly more in conditions utilizing game fiction than learners in conditions with no game fiction. This is consistent with finding by Landers and Armstrong (in press) who found that learners anticipate more satisfaction and enjoyment from narrative-gamified training compared to more traditional training methods. Although research supporting the narrative hypothesis suggests that the effects of game fiction on learning are direct, the narrative hypothesis itself suggests that game fiction impacts learning through mediating processes (Adams et al. 2012). Game fiction may impact the motivation to learn, as narrative is often considered a motivating element in computer games (Adams et al. 2012). Besides motivation, game fiction could potentially impact other mediating variables such as learning engagement or distraction. If game fiction increases engagement with the instructional content by making the content more interesting or relevant to the learner, learning outcomes should improve. However, if game fiction increases distraction, learning outcomes might be worse than learning contexts without game fiction. Adding game fiction to a learning context increases the amount of irrelevant information presented, which may detract focus from the content itself (Adams et al. 2012).

A simple way of adding game fiction to a learning context is by creating a narrative. Existing instructional content can be converted into a simple story. Thorndyke (1977) provides ten rules that simple stories must follow, which together create an outline structure for simple stories. First, the setting is established, consisting of characters, location, and time. Next, a theme must be presented, representing some overarching goal within the story. The plot of the story consists of multiple episodes where characters experience events along the way to the thematic goal of the story. Instructional content can be embedded at multiple points throughout the story. Each episode or event characters experience might present different content. The actions of the characters might represent different methods or procedures for completing a process, like a skill-based learning outcome (Kraiger et al. 1993). This process of embedding content within a story in an engaging way is likely to depend heavily upon writing skill. Practice or experience with writing along with strong instructional design principles are needed to make such a form of gamification effective. Once the narrative has been introduced, its impact on an anticipated moderating behavior – such as identification with the protagonist – can be measured and its effect on learning considered.

## 21.8 Social Constructivism

Constructivism proposes that all meaning from learning is created by learners rather than individually (Kraiger 2008). This is often stated in contrast to objectivist learning, which involves an instructor transmitting objective facts, with an implicit assumption that the learner's goal is to simply absorb information shared by an expert. From an objectivistic point of view, facts are objective, it is the instructor's responsibility to transmit those facts, and learning objectives are the same for all learners. In contrast, constructivists view knowledge as something that the learner creates and builds upon individually. Each learner brings different levels of previous knowledge and different motivations for learning, ultimately developing a personal understanding of course material. From a constructivist scenario, instructors facilitate (rather than deliver) learning. Ultimately it is the learner who must choose to build and create meaning from the content.

Constructivism can be broadly divided into two major perspectives: cognitive and social. Cognitive constructivists believe that the individual is the key, that each learner constructs their own personal reality using the information they have learned. In contrast, social constructivists believe that individuals create meaning from each other, instructors, and their various interactions. Thus, the goal of social constructivists is to create environments in which learning can be achieved in several ways: through learner-content interactions, learner-instructor interactions, and learner-learner interactions. It is important to note that simply enabling social interaction via technology (e.g., the existence of an interactive chat room or forum) is not enough: social interaction first requires a psychological environment where there is group trust and cohesion, and communication is a norm (Kreijns et al. 2003).

Existing evidence for social constructivism is sparse because it is a theoretical perspective in the creation of course materials versus a specific psychological process or theory. Instead, social constructivism is realized through the deployment of socially oriented educational interventions, intended to encourage peer learning through expression (Powell and Kalina 2009). Through this lens, quite a variety of evidence is available. For example, Durlak et al. (2011) found that social and emotional learning programs improved knowledge and skill development, attitudes, and behavioral change, in a meta-analysis of 213 educational programs involving 270,034 students. There is less clarity on the precise mechanism by which such programs influence these outcomes, although two possibilities have emerged. First, the effects may be due to social facilitation. For example, students are more motivated in the context of self-determination theory (discussed earlier) when their behaviors are socially related to others. This is supported by evidence suggesting motivational aspects to social elements of learning (Urdan and Schoenfelder 2006). Second, the effects may be more cognitive in nature, because the social context of learning actually makes it easier to learn material. Specifically, because knowledge is socially situated, learning it in a social context is cognitively simpler than learning it outside of a social context and then connecting how it is related later.

### *21.8.1 Applying Social Constructivism via Human Interaction Game Elements*

The human interaction category encompasses “the degree to which players interact with other players in both time and space.” A high amount of human interaction in a gamified learning setting consists of learners collaborating, competing, or simply existing alongside other people through in-person or technology-mediated communication. An extremely low (or nil) amount of human interaction in a gamified learning setting would isolate the learner from communicating with others. Importantly, human interaction refers to interactions with people in all roles whether instructor, peer, team member, mentee, or anything else.

Most common learning approaches have some degree of human interaction already. For example, in a typical lecture, students are still able to observe their peers’ learning processes and interactions with the instructor. To determine the impact of human interaction as a game element category, it is important to distinguish between the effects of human interaction and the particular interactions they might bring. An instructor delivering course material increases human interaction but also delivers course material; these effects should be distinguished carefully when considering gamification with human interaction.

According to social constructivist learning theory, more human interaction during the learning process should lead to increased learning outcomes. One way this can be achieved is by creating an environment of learner interdependence and communication. Learners who communicate in order to accomplish their objectives establish a communication norm and are thus more likely to communicate casually or about other topics (Kreijns et al. 2003). In this context, increased communication is a gamified learning mediator, between the use of human interaction and learning. Another way to gamify with human interaction and increase learner interdependence is via competition, which combines human interaction with conflict/challenge. For example, collaborative teams might compete against each other in a presentation or quiz. This tactic is commonly seen in American classrooms when instructors divide the class into teams to play a Jeopardy-style quiz game in preparation for a test. The winning team is sometimes awarded extra credit points, early recess, candy, or some other token reward, but such rewards may not be necessary (see the earlier discussion of goal-setting theory). Winning may be its own reward. In this context, participation in the learning game might be the key mediator. If the learning environment is structured such that team interdependence is a must, then competition between teams should strengthen the communication networks and cohesiveness of the group (remember, cohesiveness and communication norms are critical to the success of social constructivism in technologically mediated learning environments). Thus, learning environments should be structured in a way that encourages learner-learner interactions.

## 21.9 Conclusion

In the preceding sections, we have described the theory of gamified learning and provided specific psychological theories that support particular game element categories in gamification interventions. Importantly, little empirical research is available supporting these specific pathways. Instead, we have relied on existing evidence from related fields to support these links. To actually evaluate the success of such interventions, it is necessary to conduct a rigorous empirical study of observed effects, and here we describe an outline for such efforts.

In terms of research design, it is critical to determine the particular game elements targeted, categorize them in terms of the framework displayed in Table 21.1, and then use an appropriate experimental design to isolate the effects of these elements. True experimentation, where learners are randomly assigned to experience either the gamification intervention (consisting of the isolated element) or no gamification intervention, is the premiere choice. Such an approach supports conclusions regarding causal effects of the gamification intervention on both the intermediary behavior and on learning. If experimentation is not possible, quasi-experimentation is the backup choice. There are many ways to test gamification quasi-experimentally depending on the precise research context, and this approach is most common in field settings among practitioners. If this approach is required, it is recommended to consult sources on quasi-experimental design for advice on such approaches (e.g., Shadish et al. 2002). In either case, the intermediary variable, whether mediator or moderator, should be measured, preferably before learning occurs.

In terms of statistical analysis, there are objectives of interest which require distinct analysis. To address the practical question of overall impact, the learning outcome targeted should be regressed on a dummy-coded (i.e., 1 or 0) gamification variable. This will produce a regression weight ($b$), which represents the amount of change expected in the outcome variable as a result of gamification. Importantly, this result does not need to be statistically significant for the gamification to have been successful. Instead, it suggests that gamification's effect given the research design was too small to detect. To determine actual impact, the specific design must be analyzed appropriately. If testing a mediational hypothesis, the bootstrapped confidence interval of the indirect mediating effect must be calculated. Presently, this is commonly done using either structural equation modeling or by using an SPSS or SAS macro developed by Preacher and Hayes (2004). If testing a moderation hypothesis, hierarchical multiple regression should be used to test the incremental effect of moderation, per the recommendations of Baron and Kenny (1986). Specifically, a model $R^2$ should first be calculated from the regression of the learning outcome on both the gamification dummy variable and moderator variable. Second, a model $R^2$ should be calculated from the regression of those variables plus an interaction term, calculated as the product of the dummy variable and moderator. Third, the change in $R^2$ should be evaluated for significance. A significant change in this $R^2$ indicates that the moderator term adds value in the prediction of learning outcomes.

Overall, it is only through careful, systematic exploration of specific game elements and their likely psychological mediators and moderators that we will ever be able to provide consistent, reliable guidance to those working in the field. In the end, the only value gamification can bring is if learning outcomes, whether reactions, knowledge gained, or skills gained, actually increase as a result of such interventions. If we cannot provide such evidence, there is no point in wasting time on developing gamification interventions, regardless of how easily implementable researchers and practitioners can make them. It is only through a body of thoughtfully designed and empirically supported evidence that we will determine if gamification is truly a useful instructional design tool or ultimately nothing more than a fad, and we hope that the present chapter provides researchers and practitioners with the tools to find out.

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# Chapter 22
# Why Gamification Fails in Education and How to Make It Successful: Introducing Nine Gamification Heuristics Based on Self-Determination Theory

**Rob van Roy and Bieke Zaman**

**Abstract** Gamification, a design technique that uses the motivational elements of games in other contexts, is increasingly looked at as a possible solution to the dropping levels of motivation observed in learners. However, previous research has presented mixed results as to the demonstration of whether gamification in education works or not. To better evaluate the potential of gamification, we argue that it is important to first focus on *how* gamification works. This chapter contributes to this discussion by asking three research questions, starting by specifying "What is gamification?" (*Q1*), to then revealing "How does gamification work?" (*Q2*). Looking at gamification from the perspective of self-determination theory, we show that various types of motivation guide people's behaviour differently and point to the importance of basic psychological need satisfaction. Furthermore, the answers to our first two research questions will explain why adding game elements as external, meaningless regulations is likely to cause detrimental effects on learners' intrinsic motivation. Finally, by cumulating these theory-informed insights, we address our last research question "How can gamification design be improved?" (*Q3*) and define nine gamification heuristics that account for (the interplay between) design, context and user characteristics. As such, this chapter forms a guide for researchers, educators, designers and software developers in fostering a promising future generation of gamified systems that resonates our plea for theory-driven design.

**Keywords** Gamification • Education • Motivation • Self-determination theory • Basic psychological needs

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## 22.1 Introduction

In the last decade, there has been a remarkable upsurge of the use of badges, leaderboards, challenges and other game elements in a variety of software, apps and websites. This phenomenon is referred to as gamification, a design technique that sets out to implement the compelling elements of games in other systems. Well-known examples of gamified systems are the sport app *Nike+ Running*™, the professional social networking site *LinkedIn*®, the navigation app *Waze*®, the online learning platform *Khan Academy*® and the language-learning app *Duolingo*®.

In this chapter, we focus on gamification in an educational context. We will explain that for the research field to mature, we should first achieve a deeper understanding of *how* the interaction with a gamified system may unfold in education, before we can address the question *whether* gamification works. Sophisticated theoretical underpinnings concerning gamification's direct influence on learners' motivation can help in gaining this much-needed understanding. This chapter aims at providing such theoretical insights and extends this knowledge by formulating concrete design guidelines that are likely to bring forth advanced and effective implementations of gamification in educational contexts.

This chapter is structured around the following three main research questions:

*Q1* What is gamification?
*Q2* How does gamification work?
*Q3* How can gamification design be improved?

In the first section of this chapter, we answer the first research question (*Q1*) by defining gamification and discussing its potential in an educational context. Then, we rely on self-determination theory to explain the psychological processes underlying motivation and gamification, hereby addressing the second research question (*Q2*). The last section deals with the third research question (*Q3*) and discusses how our theoretical findings yield concrete design implications. More particularly, we end this chapter by introducing nine theory-based gamification heuristics.

## 22.2 *Q1* What Is Gamification?

In academia, gamification is generally defined as "the use of game design elements in non-game contexts" (Deterding et al. 2011, p. 9). Notwithstanding the consensus in definition, the operationalization of what exactly constitutes a gamified system remains a challenging endeavour. For instance, the definition does not specify the number and characteristics of the game design elements that have to be implemented in a system to label it gamified. It does also not put forward distinctive criteria to determine when a system stops to be a gamified one and when it is to be conceptualized as a full-fledged game instead.

Nowadays, gamification seems to be a buzzword, as something new and innovative to explore. However, the idea of gamification is not new. Looking beyond the recent booming of the academic and industrial discourses surrounding gamification (for an overview of the events leading to this boom, see Deterding 2015a, p. 30 and onwards) shows us that the practice of gamifying our lives is not new. It originated from the popularity of both offline and online games. People from various ages all over the world spend hours playing games without being forced to do so. For example, a recent survey concluded that about half the active European population plays video games, and this is for an average of more than 7 h a week (Interactive Software Federation of Europe 2016). This illustrates that games are inherently fun, motivating users to keep playing without any external pressure (Burguillo 2010; C.-H. Su and Cheng 2015). For years, practitioners and researchers have been experimenting with identifying what it is that makes games motivating, trying to use this knowledge to restructure other activities to make them as motivating (e.g. see the early work of Thomas Malone; Malone 1980, 1981, 1982). For instance, already from a nondigital era onwards, teachers have been rewarding children with stickers (*badges* in gaming jargon) when they performed well at school (Blohm and Leimeister 2013). However, it is only since the recent digitalization that the interest in gamification boomed in a variety of industrial and academic contexts (for an overview, see Hamari et al. 2014 or Seaborn and Fels 2015). Especially in education, gamification techniques are being welcomed as a promising strategy to enhance motivation (Ramirez and Squire 2015) which is found to be one of the most important determinants of educational success (Abramovich et al. 2013; Buckley and Doyle 2014; Taylor et al. 2014). Gamification is then thought of as presenting a potential solution to the dropping levels of learners' motivation (Busse and Walter 2013; Darby et al. 2013; Lepper et al. 2005; Pan and Gauvain 2012).

Research investigating the potential of gamification in educational contexts shows a scattered picture (see, e.g. de Sousa Borges et al. 2014 or Dicheva et al. 2015). Some studies have reported on positive effects of gamification on leaners' performance (e.g. in terms of better grades; see C.-H. Su and Cheng 2015) and study behaviour (e.g. in terms of the effort put into finishing assignments, see Barata et al. 2013). Others have found that the addition of badges to an online learning tool drove learners to contribute more and to be more engaged compared to a situation in which no badges could be collected (Denny 2013). Other studies have pointed to mixed results (see, e.g. de-Marcos et al. 2014), including instances in which no significant difference between a gamified and a non-gamified learning context could be observed. Although Hakulinen et al. (2013) found small differences in learning behaviour between learners who were rewarded with badges for doing exercises and those who were not, they did not find any difference in the grades obtained. Yet other studies revealed that the implementation of gamification in education might even yield undesirable effects. To illustrate, in some studies, it was found that students performed worse in a situation with badges, trophies, challenges, a leaderboard and levels compared to peers who weren't exposed to these game elements (de-Marcos et al. 2014; Domínguez et al. 2013). Non-gamified activities were also found to be more motivating compared to the gamified ones (Domínguez et al. 2013).

In an attempt to clarify these inconclusive results, some authors have argued that the desirable motivational effects are temporary in nature and that they can be ascribed to a novelty effect caused by adding digital and/or game elements in an educational context (Attali and Arieli-Attali 2015; Hanus and Fox 2015; Koivisto and Hamari 2014). Others have posited that the undesirable effects are rather a result of flawed design (Domínguez et al. 2013; Rojas et al. 2013). By simply adding points and leaderboards to a system, it is then argued, gamification is reduced to a meaningless *pointification* with no or aversive effects. Likewise, Domínguez et al. (2013) have pointed to flawed designs and the absence of a "sound pedagogy" (p. 9) as the origin of undesirable results.

In order to contribute to this discussion and better understand the various ways in which gamification can and cannot work, we argue that it is of utmost importance to first understand *how* this design technique is likely to work. To date, most gamification researchers have been concerned with a demonstration of *whether* the implementation of gamification yields the desired study behaviour and performance effects (Hamari et al. 2014). In doing so, however, they have been turning a blind eye to motivation as a prerequisite influencing a learner's performance. As a consequence, we are still lacking the explanatory insights on *how* and *under which conditions* gamification can work (Deterding et al. 2011; Richter et al. 2015).

## 22.3 *Q2* How Does Gamification Work?

Insights into the psychological concept of motivation will help us to better understand how gamification works. In this context, the perspective of self-determination theory (SDT; Deci and Ryan 2004), a research-based theory that has found general acceptance in motivational research both within and beyond the domain of education (Reeve 2004), is particularly instructive. SDT provides insights in the psychological processes underlying gamification (Deterding 2015b; Seaborn and Fels 2015), because it sheds a multidimensional light on people's motivations, which is explanatory for the variety in corresponding behavioural outcomes (Ryan and Deci 2000a).

### *22.3.1 Intrinsic, Extrinsic and Amotivation*

Motivation describes the psychological processes that direct and energize behaviour (Reeve 2004). It is motivation that steers people's actions, as such being one of the essential driving factors of the effort learners put into study activities. The basic premise of SDT is that it is not the amount of motivation but the particular

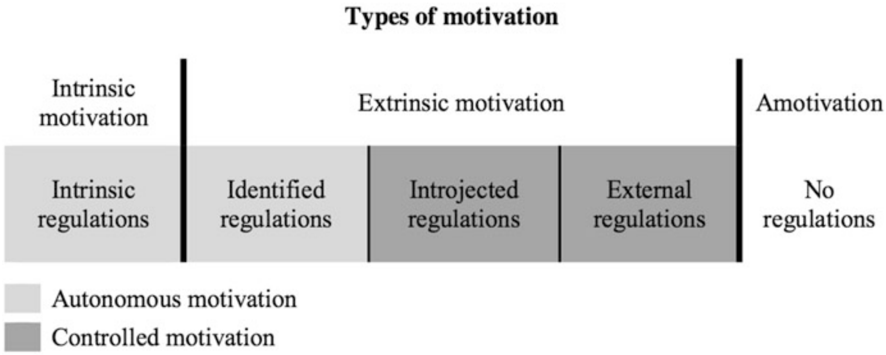


**Fig. 22.1** The different types of motivation (Based on Deci and Ryan 2004, p. 16)

nature of distinct motivational types that holds the most predictive and explanatory power as to how people behave (Deci and Ryan 2008a). In explicating the SDT principles, Deci and Ryan distinguish three main types of motivational states, namely, intrinsically motivated, extrinsically motivated and amotivated states (Deci and Ryan 2004). Figure 22.1 visualizes how intrinsic and extrinsic motivation form two poles of a spectrum, with on one side motivation caused by intrinsic regulations and on the other side motivation caused by external regulations; these two types of motivation are distinct from amotivation, for which there are no regulations present.

Amotivated signifies the characteristic of people who have no intention to perform a particular behaviour (Deci and Ryan 2004; Otis et al. 2005; Vansteenkiste et al. 2009). In an educational setting, this would imply that learners are not driven to execute an educational activity; they are unmotivated. Conversely, intrinsically and extrinsically motivated people do experience a certain drive to perform the action in question. The difference between the latter two types of motivation can be ascribed to their origin.

On the one hand, intrinsic motivation is derived from intrinsic regulations that originate from pleasure and interest found in the activity (Deci and Ryan 2004; Otis et al. 2005; Vansteenkiste et al. 2009). In an educational context, this happens when learners enjoy the engagement in an educational activity for no other reasons than for themselves. Because intrinsic motivation is fully autonomous, it is seen as the ideal motivational type to drive actions (Vansteenkiste et al. 2009). On the other hand, extrinsic motivation is derived from extrinsic regulations that are not related to the activity concerned (Deci and Ryan 2004; Otis et al. 2005; Vansteenkiste et al. 2009). These regulations are external cues that form an outside pressure controlling someone to conduct a desired behaviour. Examples of such external cues are punishments, rewards, feelings of shame and anticipated consequences.

### 22.3.2 The Internalization Processes of Extrinsic Regulations

SDT postulates that people who experience pressure from external regulations – or in short, who are extrinsically motivated – are very likely to feel an innate need to internalize these regulations and make them a part of themselves (Deci and Ryan 2004). If and to which extent the internalization of these regulations takes place depends on the degree to which their psychological needs are supported (*see further*). The more successful the process of internalization, the more extrinsic regulations echo the characteristics of intrinsic motivation, and thus the more someone's motivation moves towards intrinsic motivation on the continuum (see Fig. 22.1).

In SDT, three distinct subtypes of extrinsic motivation[1] are put forward, depending on the successfulness of the internalization process (Deci and Ryan 2008a). As a first subtype, external regulations mark a situation in which no internalization takes place (Buckley and Doyle 2014; Deci and Ryan 2004; Vansteenkiste et al. 2006). In an educational context, this is the case when a learner does not concur with the reasons for doing the activity and only conducts the expected behaviour in order to avoid punishment or get rewarded (Vansteenkiste et al. 2009). Introjected regulations, as a second subtype of extrinsic motivation, are characterized by a small amount of internalization (Deci and Ryan 2008a). In the latter situation, extrinsic cues are somewhat accepted but not yet considered to be part of the learner's self (Buckley and Doyle 2014; Deci and Ryan 2004; Vansteenkiste et al. 2006). People are thought to be driven by introjected regulations when they perform an activity to avoid shame or prove competence (Vansteenkiste et al. 2009). The last subtype of extrinsic motivation refers to situations in which external regulations are accepted and deemed as personally important, hereby becoming identified regulations (Buckley and Doyle 2014; Deci and Ryan 2004; Vansteenkiste et al. 2006). This happens when people endorse an activity, but rather than performing it for the activity itself, they act because of the desirability of the outcomes (Vansteenkiste et al. 2009). Although identified regulations resemble intrinsic regulations, they are still extrinsic in nature as the reason for performing it lies beyond the activity (Kyndt et al. 2011; Vansteenkiste et al. 2006).

In the hypothetical example presented in Box 22.1, we learn about a situation in which four colleagues are all about to start learning a foreign language. Alicia is intrinsically motivated. Even though Ben, Charlie and Daisy are extrinsically motivated, various regulations are at stake that will eventually guide their behaviour in a different way.

[1]Originally, Deci and Ryan (2004) defined four different types of extrinsic motivation, but in later years, various academics have combined identified and integrated types of regulations because of their resemblance (e.g. Vansteenkiste et al. 2009).

**Box 22.1: Meet Alicia, Ben, Charlie and Daisy, Four Colleagues Who Are Driven by Intrinsic, Identified, Introjected and External Regulations, Respectively**

Meet Alicia, Ben, Charlie and Daisy. They are all about the same age, live in San Francisco, California, and work as client representatives at a flourishing start-up. The four colleagues all speak English, French and German fluently. Because of the rise in European clients, and in particular Spanish customers, they decide to start following evening classes to learn how to speak Spanish. But what drove them to take this decision? Depending on the reasons they hold, they are motivated in qualitatively different ways. Let's take a look at their motives.

*Alicia – Intrinsic regulations*. Alicia really likes learning new languages, learning new vocabulary by heart, getting into grammar rules and grasping how a language developed over the years. Because Alicia's primary motive to learn Spanish is the joy she experiences while doing so, she is thought to be driven by *intrinsic regulations* and feels autonomously motivated.

*Ben – Identified regulations*. Ben is looking for a new job and is considering to apply for an interesting position of a colleague who is about to retire. One of the job requirements is to speak Spanish. To make sure he will be considered for this job, he decides to learn Spanish. Although Ben endorses learning Spanish, he primarily starts studying it in order to achieve his personal, valued goal of enhancing his career. Therefore, Ben derives his autonomous motivation mostly from *identified regulations*.

*Charlie – Introjected regulations*. In the office, the atmosphere among the four colleagues is often competitive. When Charlie finds out that Alicia, Ben and Daisy are going to take Spanish classes, he decides to do the same, convinced that this is a great opportunity for him to show off his language skills. Charlie's main motivation for following the course is not learning Spanish, as such, but merely enhancing his self-esteem. Therefore, he is motivated by *introjected regulations*, and experiences controlled motivation.

*Daisy – External regulations*. The government has enacted a law which states that every California-based enterprise should have at least four employees who speak Spanish. The CEO decides that Daisy should learn Spanish too, promising her a substantial promotion if she does so successfully in about 2 months. Daisy starts taking the course because she is promised a reward. She is therefore driven by *external regulations* and thus by controlled motivation.

### 22.3.3 Autonomous Motivation Outperforming Controlled Motivation

The fine-grained SDT insights regarding people's motivational (sub)types and the internalization processes of extrinsic regulations prevent us from considering motivation as a homogeneous construct. Moreover, as is illustrated in the example in Box 22.2, these theoretical insights help us to better understand and predict people's behaviour according to their position on the continuum between intrinsic and extrinsic motivation (Ryan and Deci 2000a). Finally, it presents us with information to judge the desirability of a particular type of motivation.

Research has shown that people who are primarily motivated by external and introjected regulations behave in similar ways. This behaviour is different from the behaviour of people who are mainly driven by identified and intrinsic regulations. Therefore, external and introjected regulations are often categorized together based on the shared characteristic of being regulations for *controlled motivation*. Identified and intrinsic regulations, then, are grouped together as both presenting prerequisites for *autonomous motivation* (Kyndt et al. 2015; Vansteenkiste et al. 2009). These two categories of controlled versus autonomous types of motivations are illustrated in Fig. 22.1 and in Box 22.1.

Compared to controlled motivation, autonomous motivation is linked to more psychological well-being, persistence and better performance in different contexts (Deci and Ryan 2008a; Peng et al. 2012). Contrarily, controlled motivation is found to be more likely to quickly vanish when the external control is removed (Richter et al. 2015). This is not the case for identified regulations that are internalized; they are not dependent on the existence of particular external cues.

These insights have brought SDT researchers to conclude that autonomous motivation is the desired type of motivation (Deci and Ryan 2008a; Vansteenkiste et al. 2009), whereas controlled motivation, as the unstable determinant of behaviour, is considered as the least desired type of motivation. This explains why in an educational context, autonomous types of motivation have a more long-lasting positive effect on learning outcomes, grades and participation frequency (Hanus and Fox 2015; Kyndt et al. 2011; Liu et al. 2012), compared to controlled motivation. It further helps us understand why increased levels of controlled motivation are likely to go hand in hand with a decrease in learners' accomplishments (Kyndt et al. 2011), and why learners who are driven by controlled motivation are likely to lose their motivation and become amotivated when external regulations are removed (Richter et al. 2015). Concrete examples of these complex dynamics between learners' motivations and their study behaviour are provided in Box 22.2.

**Box 22.2: The Takeover, How Controlled Versus Autonomous Types of Motivation Steer People's Behaviour in a Qualitatively Different Way**
Four weeks after Alicia, Ben, Charlie and Daisy started following the Spanish course, the company is taken over by a large multinational. Alicia, Ben, Charlie and Daisy will soon be transferred to different offices all over the USA. As several of the new colleagues already speak Spanish fluently, there is no need for them to learn this language anymore.

*Charlie and Daisy – Controlled motivation*. Both Charlie and Daisy lose their motivation to complete the Spanish course, due to the removal of the external control. Daisy's promotion has been withdrawn, and she decides to stop taking the classes altogether. Charlie doubts what to do, knowing that he will see his former colleagues less often. He decides to take up the course again when there are new opportunities to show off his Spanish skills.

*Ben – Autonomous motivation* (*identified regulations*). For Ben, the direct external motivator to learn Spanish is removed because he can no longer apply for the vacancy at his old office. Nevertheless, he is still one of the most motivated students in class. Ben values studying Spanish primarily to enhance his career and is therefore still driven by identified regulations to complete the course.

*Alicia – Autonomous motivation* (*intrinsic regulations*). Alicia was very motivated to learn Spanish from the start and truly enjoys studying it. The reorganization does not change the fact that she enjoys learning new languages. Therefore, the intrinsic regulations Alicia holds are not affected by the takeover.

### *22.3.4 Basic Psychological Needs Co-shaping Motivations*

The condition "essential [...] to experience growth, mastery, integrity and well-being" (Ryan and La Guardia 2000, p. 149), SDT argues, is that psychological needs are satisfied. With every person having an innate drive to flourish (Deci and Ryan 2008a; Gunnell et al. 2013), activities fulfilling these needs are thought of as particularly sparking autonomous types of motivation. The three psychological needs put forward in SDT are autonomy (related to volition), competence (related to the perception of being able to successfully complete a task) and relatedness (i.e. the feeling of belonging to a group of people) (Deci and Ryan 2004). These psychological needs are found to hold universal merit, deeply nested in people across different cultures and ages (Ryan et al. 1997; Ryan and Deci 2000a), but the way in which these needs are supported is culture specific (Deci and Ryan 2008a). Moreover, these psychological needs shape the particular manifestations of people's motivations. For instance, research shows that people tend to internalize external regulations quicker and more thorough when they come from friends or family, a phenomenon caused by the feeling of relatedness (Ryan and Deci 2009).

In general, in the case of need fulfilment, internalization processes are likely to occur, resulting in enduring motivation. Contrarily, activities and contexts experienced as thwarting psychological needs are likely to diminish initial levels of autonomous motivation (Deci and Ryan 2008a; Kyndt et al. 2015; Vansteenkiste et al. 2009). In Box 22.3, we exemplify how these basic psychological needs are related to the different types of motivation. It demonstrates how the degree to which people perceive a particular activity and its surroundings as contributing to satisfying their basic psychological needs determines how the internalization processes of external regulations will unfold (Deci and Ryan 2008a) and consequently whether the motivation to pursue the activity in question can be conceptualized as autonomous or controlled in nature (Deci and Ryan 2008a; Kyndt et al. 2015; Vansteenkiste et al. 2009).

**Box 22.3: The 6-week Turning Point, Exemplifying How Basic Psychological Needs Co-shape People's Motivations**

Six weeks after the start of the course, Alicia and Charlie are still actively participating in class. Charlie considered quitting but soon realized that by improving his Spanish skills, he can also show them off to his new colleagues. Alicia is still genuinely interested in learning Spanish.

*Alicia – Intrinsic regulations and the need for competence*. As the course continues, Alicia finds it more and more difficult to complete the assignments and to keep up with the pace of the classes. Because she was very motivated to learn Spanish when she signed up for the course, she chose to start at the advanced level instead of taking the introductory course. Although she was able to quickly catch up with the basics on her own, she now finds herself in the position that her classmates are speaking Spanish significantly better. Alicia starts to doubt her language skills, and as such her feeling of competence is thwarted. Her initial enjoyment decreases; she loses her autonomous motivation and starts to think about quitting the course.

*Charlie – Introjected regulations and the need for relatedness*. Although Charlie's initial motivation to take the Spanish course was the opportunity to brag about his newly acquired language skills, he eventually starts to enjoy the classes because of the teamwork involved. This way, his main reason for going to class has gradually shifted from mere ego boosting towards the enjoyment of studying in a group. Consequently, his feelings of belongingness and relatedness towards his classmates make him more autonomously motivated than before.

### 22.3.5 A Self-Determination Theory Perspective on (Gamified) Motivation in Education

Gamified systems that provide learners with feelings of autonomy, competence and relatedness are likely to foster autonomous motivation (Mekler et al. in press), hereby both causing and explaining enjoyable, motivating and engaging experiences (Deci and Ryan 2008b; Peng et al. 2012). For the same reason, it has been concluded that any "future intervention effort that intends to capitalise on the motivational pull of video games should purposely include game futures that have the potential to increase need satisfaction" (Peng et al. 2012, p. 192). Unfortunately, the state of the art of gamification systems implemented in educational contexts has presented very little to no evidence of supporting learners' basic psychological needs. The design practice of gamified systems shows a general overreliance on external motivating regulations. Many designs only include decontextualized points and badges, which are easy and straightforward to implement in practice. Moreover, most gamification research goes out from some sort of gut feeling of the researcher neglecting motivational theory (Seaborn and Fels 2015). Researchers who do address motivational theory (in most cases SDT) do so in a popularized, simplified way (Deterding 2015b; Seaborn and Fels 2015).

By considering this common practice of designing gamification as an implementation of external regulation, SDT helps us to understand the often undesirable side effects. Based on SDT, we know that when students are introduced to external forces as a way to steer their study behaviour, they are more likely to feel less autonomous as a learner and perform study activities primarily to receive the promised external rewards. Additionally, in such a situation, the controlled motivation may also undermine any pre-existing autonomous motivation. Learners may then start ascribing their motivation to the added external regulations, which reduces or even removes any initial, intrinsic drive (Cameron et al. 2005; Filsecker and Hickey 2014). Consequently, feelings of autonomy may further descend, hereby even diminishing any intrinsic motivation left, so that eventually the learner's motivation changes from intrinsic to controlled motivation (Glover 2013; Tohidi and Jabbari 2012).

The latter fundamental motivational process in which initial intrinsic motivation is overruled by external regulations has been described in research as the *overjustification*, *undermining* or *corruption effect* (Lepper et al. 1973; Lepper and Henderlong 2000; Weibel et al. 2010) and is demonstrated in Box 22.4.

**Box 22.4: Supplementary Exercises, Unfolding the Process of Overjustification When Intrinsic Motivation Is Overruled by External Regulations**
*Alicia – Intrinsic regulations being overruled by external regulations*. After catching up with her fellow students, Alicia is asked to participate in a

(continued)

**Box 22.4:** (continued)
nationwide contest designed for students learning foreign languages, which awards the winner a cash prize of $ 10,000. In order to stand a chance to win the prize, Alicia's teacher tells her to practise her skills a lot, supplying her with supplementary exercises. Initially, Alicia likes making the exercises, but after a couple of days, she starts feeling washed out. She starts to experience the once-in-a-lifetime chance to win $ 10,000 as the main motivator to keep going, replacing her initial intrinsic motivation of enjoying to learn a new language. The cash prize starts to serve as the controlling force, driving Alicia's study behaviour. The reason for learning a new language has shifted from a mere interest in the activity to the external control caused by the potential promised reward.

Exclusively relying on the implementation of external regulations in gamification design isn't always causing a problematic motivational scenario, though (Deci and Ryan 2008a; Hidi 2015). When motivational cues that are originally external in nature appeal to the psychological needs of the actor, the external regulations will be thoroughly internalized resulting in autonomous motivation (Deci and Ryan 2008a). The latter process also explains why an absence of an overjustification effect is happening in scenarios where external regulations successfully support people in their basic psychological needs. As such, it can be inferred that external regulations, and by extension the typical gamification implementations, do have the potential to intensify feelings of autonomous motivation on the condition that people perceive them as appealing to their psychological needs. In an educational context, such need support is linked to various positive educational consequences, like improved grades and better understanding of the course materials (Deci and Ryan 2015; Mekler et al. in press; Ryan and Deci 2009).

## 22.4 *Q3* How Can Gamification Design Be Improved?

Based on SDT, we argue that gamification can motivate learners in a qualitative good way when it supports the three basic psychological needs innate to everyone, as such echoing earlier statements of Peng and Mekler and their colleagues (Mekler et al. in press; Peng et al. 2012). Acknowledging that this is a relatively vague design guideline, we will reflect on the concrete design implications of our theoretical insights by introducing nine theory-based gamification heuristics. This way, we answer the third research question on how to improve gamification design from the perspective of the system characteristics of a gamified system, as well as the situational factors that co-shape the effects of gamification, being user (in this case the learner) and context characteristics.

### 22.4.1 Supporting Basic Psychological Needs

In this section, we will first provide a more in-depth understanding of the three basic psychological needs and zoom in on their interplay. Then, we will consider how game elements can be selected in order to support learners in their psychological needs. During this discussion, we present evidence from both video game and educational research.

#### 22.4.1.1 Need for Autonomy

The need for autonomy refers to feelings of volition (Deci and Ryan 2004). When feeling autonomous, the learner perceives no demanding external constraints or pressure. Performing the activity then goes out from the perception of a free choice and complies with the learner's sense of self. Perceived autonomy is an important antecedent for autonomous motivation. In educational contexts, teachers and parents who provide children with choices and support them in their initiatives are found to positively stimulate the autonomous motivation to engage in learning behaviour, more than teachers and parents who are strict and controlling (Jang et al. 2009; Rigby and Ryan 2011).

The implications for the design of gamified systems in education are that learners' need for autonomy is to be accounted for at design time. To illustrate, when a gamified system provides a variety of meaningful, learning supporting challenges ready to be handpicked by the learner, this system is likely to support autonomy. However, if the challenges form an obligatory part of the course, learners will rather feel externally controlled by the obligation to complete the challenges and as a result may start feeling anxious and losing autonomous motivation. Therefore, the first heuristic we propose is:

**#1 Avoid Obligatory Uses**
Avoid forcing the user to use (a part of) the gamified system in order not to give them the feeling of being controlled.

Providing options to choose from is often thought of as supporting people's need for autonomy too. Previous research has confirmed that a moderate amount of choice is likely to incite the perception of being autonomously motivated (Deci and Ryan 2008a; Deterding 2015b; Peng et al. 2012; Rigby and Ryan 2011). People can also feel autonomous when there is no choice situation, though. Rigby and Ryan (2011) point to examples in which people are only presented with a single option and still feel autonomous. If the single available option is one complying with the user's internal values, then it presents people with a meaningful and valued perspective. For example, when a teacher instructs students to write an essay on a specific topic that aligns with their interests, they can still feel autonomous, even though they were not provided with a choice. Therefore, when the specific context inhibits the complete removal of the feeling of obligation (e.g. in formal education), action should be undertaken to make the activity's alignment with the user's interests and needs explicit.

Conversely, too many choices can yield negative effects, known as *The Paradox of Choice* (Schwartz 2009). The reasoning then goes that when someone is presented with many different but equivalent options to choose from, they are likely to feel anxious to make a decision, feeling uncomfortable because they experience loss with respect to the options that could not be selected, fearing to miss out (Ryan and Deci 2006). Reutskaja and Hogarth (2009) experimentally demonstrated that people's satisfaction with a task follows an inverted U-shaped function of the amount of choices provided. In a context of gamification in education, these insights stipulate not to provide learners with an endless stream of options to choose from, as such placing them in dilemmas. Rather, the gamified system should be conceptualized in such a way that it presents at least one option that is meaningful and valuable to the future learners. Therefore, the second heuristic reads as follows:

**#2 Provide a Moderate Amount of Meaningful Options**
Find the sweet spot between supporting users' autonomy by providing them with at least one option that is meaningful and complies with their values, while avoiding placing them in a dilemma by offering too many options.

#### 22.4.1.2 Need for Competence

The need for competence refers to our desire to feel that we can successfully achieve a goal, being the master of the activity in question (Deci and Ryan 2004). The perception of competence leads to autonomous motivation. In educational contexts, learners who experience competence are found to be more persistent and have better study results than learners who feel incompetent (Rigby and Ryan 2011). The design implications for gamified systems in education are not just a matter of making the activity as simple as possible. In order to optimally motivate learners, tasks should be designed in such a way that they just fall outside the learners' comfort zone while still being perceived as attainable. Malone talks in this respect about tasks with "an appropriate difficulty level" (Malone 1980, p. 163, 1981, p. 358). This way, learners are challenged to persevere in improving themselves (Peng et al. 2012), given the "room to grow" (Rigby and Ryan 2011, p. 16). This principle of ensuring that a task is not too easy, causing boredom, but also not too hard – causing anxiety – is well known in game research, meticulously described in the *flow theory* (Csikszentmihalyi 1990). This advice is integrated in our third heuristic:

**#3 Set Challenging but Manageable Goals**
In order to support the user's feelings of competence, create tasks that pose a significant challenge while remaining perceived as feasible to fulfil.

Another way of fostering feelings of competence is by providing constructive and meaningful feedback (Niemiec and Ryan 2009). In gamification design, this typically takes the form of badges. Compared to traditional grading in educational settings, these badges can provide more information and yield more motivational power (U.S. Department of Education 2013). More particularly, well-designed badges can give both outcome and progress feedback. Moreover, badges are not limited to evaluating strict cognitive outcomes and can more broadly and explicitly relate to the competences at stake (e.g. “You can now make a call in Spanish!”), as opposed to grades (e.g. “You obtained an A-grade for this task”) or other types of meaningless, non-informative feedback (see also Hanus and Fox 2015).

However, some types of feedback can also cause undesirable effects. These include feedback mechanisms that only focus on performance and less on competence, which is likely to be perceived as controlling, as such undermining autonomous motivation (Reeve 2004). Additionally, all types of negative feedback have been found to erode feelings of competence too, hindering learners’ autonomous motivation (Deci and Ryan 2004, 2008a).

The insights presented above imply that in gamified systems, it is advised to approach learners with positive competence-related feedback, as stipulated in the fourth heuristic:

**#4 Provide Positive, Competence-Related Feedback**
Support feelings of competence by integrating feedback mechanisms that positively inform learners about their progress in gaining competences and avoid negative feedback.

#### 22.4.1.3 Need for Relatedness

When people feel they belong to a group, their need for relatedness is satisfied (Deci and Ryan 2004). Being connected to others gives us a sense of value; it makes us happier and lets us feel better about ourselves. The positive feelings evoked by being part of a group are deepened when people share experiences (Rigby and Ryan 2011), and losing a beloved one is found to be one of the hardest things to process psychologically (Rigby and Ryan 2011).

In an educational context, learners who work together, sharing experiences and a common goal, have stronger bonds, resulting in relatedness need satisfaction and autonomous motivation. Carr and Walton (2014) found that giving students the impression that they are working together – although actually they are not – already suffices to foster feelings of relatedness.

The need for relatedness also plays an important role in video games (Rigby and Ryan 2011) and is often explicitly afforded for by design, e.g. by encouraging players to team up while tackling a challenge (Peng et al. 2012). People who feel related to others during gameplay are more likely to enjoy the game experience, feel more engaged and have higher future play motivation, compared to gamers who don't feel connected to others during gameplay (Peng et al. 2012).

As relating an activity to others supports people's feelings of relatedness, it follows that promising gamified systems are those that emphasize these links too. Previous research has indeed shown that students who used a gamified system in which social features were enabled performed better on assessments compared to those who used the gamified system without social features (de-Marcos et al. 2016). The insights mentioned above result in the definition of a fifth heuristic:

**#5 Facilitate Social Interaction**
Eliminate factors that hinder social interactions between users, and facilitate them to interact and support their feelings of relatedness instead.

#### 22.4.1.4 Interplay Between Psychological Needs

Gamified systems that support one of the three basic psychological needs are likely to provide autonomous motivation; systems that satisfy all three of them may even be more successful in motivating users, as the value of satisfying each single need adds up (Deci and Ryan 2004). One can take group work as an example (Rigby and Ryan 2011). Gamified systems that encourage group work contribute to feelings of belonging to a team (cf. need for relatedness) and lend itself well to present complex challenges that benefit from gamers who join forces, therefore letting the group's skills flourish (cf. need for competence). Last, working in a group typically implicates that new strategies can be used to attain the game's goals, hereby presenting gamers with more alternatives to choose from (cf. need for autonomy).

The fact that each single need adds up also implies, however, that in combination, one need fulfilment may equally lead to an impediment of another need fulfilment. When unfolding in everyday situations, the three psychological needs are indeed found to often clash (Ryan and Deci 2000b). For example, when a certain group challenge doesn't leave room for individual decisions and contributions, the need for relatedness might be fulfilled at the expense of an individual's need for autonomy.

The implementations of badges as a gamification strategy should also be understood as potentially pertaining to various psychological needs simultaneously. To illustrate, successful motivational badges afford constructive, noncontrolling feedback (Deci and Ryan 2008a; Deterding 2014) and support the need for competence by focusing on the achieved capabilities of the learner (*see heuristic #4*). The learner should, however, not possess all the necessary information about what activities have to be undertaken in order to achieve them, so that by no means, the badges can be perceived as controlling. In general terms, gamified systems should thus wary to not thwart one of the basic psychological needs, when trying to support another. This leads us to postulate our sixth heuristic:

**#6 When Supporting a Particular Psychological Need, Wary to Not Thwart the Other Needs**
When designing a specific element in order to support users in one of their basic psychological needs, wary to not thwart one of the other needs.

### 22.4.2 *Situational Gamification*

Gamification systems are not implemented in a vacuum; they are to be situated within the broader activity and context that is gamified, and the interaction with them unfolds depending on the characteristics of the user. In this section, we will provide more concrete design guidelines about how we can account for the way gamification may unfold in a particular context of use, accounting for aspects of the activity context, the implementation context and the user characteristics.

#### 22.4.2.1 Integration of Gamification into the Activity Context

As for the integration of gamification in education, two fundamentally different activity contexts come together. In games, motivating the player to keep playing the game is central (Deterding 2015b; Gee 2008), whereas in education knowledge acquisition is at heart. Therefore, it is beneficial to align the motivational goal of games with the learning goals, as a way to profit from the motivational pull of games in an educational context. A good gamified system should thus "*both* directly support end user activity (by ease of use) *and* facilitate it through enjoyment and motivation" (Deterding 2015b, p. 304 author's emphasis). When the alignment between both goals fails, the systems will resemble *chocolate-covered broccoli* (Deterding 2014; Lee and Hammer 2011; Linehan et al. 2011), that is, an unmotivating, unappealing activity at heart with only a fun, sweet holster. The derived heuristic reads as follows:

**#7 Align Gamification with the Goal of the Activity in Question**
Alight the motivational pull of gamification with the goal of the activity, as such tuning gamification to both facilitate motivation and goal achievement.

#### 22.4.2.2 Implementation Context and Environment

Different authors have stipulated the significant impact contexts can have on the effectiveness of gamification (Deterding 2014; Mekler et al. in press; Richards et al. 2014). For instance, as people are generally socialized with the belief that playing is inappropriate in certain contexts, for example, in class or in a bus, it follows then that the implementation of game elements in these contexts may cause confusion and embarrassment (Deterding 2014; van Roy and Zaman 2015). Moreover, in a school context, the strong emphasis on formal evaluation and learning task completion serves as a controlling force upon students that is only to be intensified when external regulations are added through gamification (Mekler et al. in press).

A school environment is often very competitive, which may form a threat for bonding with peers and consequently for the need for relatedness (Ryan and Deci 2000b; Ryan and La Guardia 2000). Conversely, competition that drives learners to be on their top behaviour can also positively influence feelings of competence and relatedness as everyone involved in the competition drives the others to improve (Rigby and Ryan 2011). Furthermore, studies illustrate that how teachers communicate with students can significantly impact the way in which learners perceive the educational context as a whole (Cheon and Reeve 2015; De Meyer et al. 2014; Haerens et al. 2015; see also Deci and Ryan 2008a). For example, Cheon and colleagues found that students of teachers who followed an *autonomy-supportive intervention programme* (ASIP) in which they are taught to provide meaningful rationales acknowledge negative feelings, use noncontrolling language, offer choices and nurture inner motivational resources (Y.-L. Su and Reeve 2010, p. 162) experienced more autonomous motivation and less amotivation (Cheon and Reeve 2015). The same positive implications of a need-supportive context on motivation and performance are reported in other domains (Cheon et al. 2015; Katz et al. 2015; see also Y.-L. Su and Reeve 2010). These results prove that small interventions can transform a context from a controlling one into a need-supportive one, in the end resulting in better learning performances. Therefore, when implementing a need-supportive gamification system, one should wary to do this in an equally need-supporting context. This leads us to the postulation of our eighth gamification heuristic:

**#8 Create a Need-Supporting Context**
In order to support the user's basic psychological needs, the gamified system should be implemented in a setting that is perceived as open and supporting as opposed to controlling.

#### 22.4.2.3 User Characteristics

People's individual characteristics affect how they experience the interaction with technology. In game research, it is found that high competitive people who are given the choice between a competitive and non-competitive version of the same exergame prefer the former version, whereas low competitive people are more likely to pick the latter alternative (Song et al. 2013). People's demographics have been found to influence the experience with gamified systems, too (Mekler et al. in press). Based on personal differences, Barata et al. (2015) defined a user typology (consisting of achievers, disheartened, late awakeners and underachievers) of users who interacted with the same gamified course in different ways. They conclude that gamification will be more effective when it accounts for the unique ways in which these different types behave on the platform (Barata et al. 2015).

An educational gamified system can anticipate on this variety in personal characteristics and the related behaviour by implementing flexible system choices, supporting users in fine-tuning system properties according to their personal preferences. The gamified system will then be more likely to satisfy people's psychological needs and provide meaningful motivational experiences to various types of users (Barata et al. 2015; Hakulinen et al. 2013). This leads to the ninth and last heuristic:

**#9 Make the System Flexible**
To account for personal differences, the gamified system should be flexible and adaptable in order to comply with the users' personal needs and preferences.

## 22.5 Conclusion

Gamification is looked at as a possible solution for the observed dropping levels of learners' motivation. However, previous research has presented inconclusive findings as to the demonstration of whether gamification works or not. In this chapter, we contribute to this discussion and argue that the wrong types of questions have been focused on. Rather than asking if gamification works, we posit that it is more instructive to first focus on *how* gamification may work. To pave the way to answer this question, this chapter scrutinized the potential of gamification in educational contexts from the perspective of self-determination theory (SDT). By doing so, we described the psychological processes underlying the working of motivation and reached a better understanding of how gamification can facilitate or hamper these processes. Based on the in-depth insights on how to spark desirable types of motivation via gamification, we postulated nine gamification heuristics (see Table 22.1). These heuristics aim for affording autonomous as opposed to controlled types of motivations and account for the importance of basic psychological needs fulfilment.

Acknowledging the importance of user characteristics (cf. *heuristic #*9) in addition to system properties (cf. *heuristics #1–7*) and contextual demands (cf. *heuristic* #8), we have shown that the phenomenon of gamification should be understood holistically. This is in accordance with Hassenzahl and Tractinsky's view (2006) that, in general, user experiences with technologies are shaped by three pillars, including system, context and user. Similarly, our heuristics should also be understood holistically. For instance, *heuristic #3* points to the design rule of creating challenging but manageable goals in a gamified system; however, whether and how users will eventually experience these goals as motivating depends on their skills and the context in which these goals are being implemented. Therefore, just like we can only design *for* user experience and not design the user experience itself, designing a gamified system is also about designing *for* motivational experiences and not about designing the motivational experiences themselves (Seaborn and Fels 2015).

Although this chapter focused on an educational context, the gamification heuristics are based on fundamental SDT insights, as such holding merit in other contexts as well. In this way, this chapter forms a first step towards a better understanding of how gamification works and arms researchers, educators, designers and software developers with well-informed rules of thumb to build desirable gamified systems. Acknowledging that our theory-based heuristics may benefit from empirical validation and refinement, we call upon future researchers to put them into practice and further extend our knowledge of gamification.

**Table 22.1** Overview of the nine theory-based gamification heuristics and the challenges they address

| Challenge | Heuristic |
|---|---|
| Support learner's autonomy | **#1 Avoid obligatory uses** |
| | Avoid forcing the user to use (a part of) the gamified system in order not to give them the feeling of being controlled |
| | **#2 Provide a moderate amount of meaningful options** |
| | Find the sweet spot between supporting users' autonomy by providing them with at least one option that is meaningful and complies with their values while avoiding placing them in a dilemma by offering too many options |
| Support learner's competence | **#3 Set challenging but manageable goals** |
| | In order to support the user's feelings of competence, create tasks that pose a significant challenge while remaining perceived as feasible to fulfil |
| | **#4 Provide positive, competence-related feedback** |
| | Support feelings of competence by integrating feedback mechanisms that positively inform learners about their progress in gaining competences, and avoid negative feedback |
| Support leaner's relatedness | **#5 Facilitate social interaction** |
| | Eliminate factors that hinder social interactions between users, and facilitate them to interact and support their feelings of relatedness instead |
| Interplay between needs | **#6 When supporting a particular psychological need, wary to not thwart the other needs** |
| | When designing a specific element in order to support users in one of their basic psychological needs, wary to not thwart one of the other needs |
| Integration of gamification into the activity | **#7 Align gamification with the goal of the activity in question** |
| | Alight the motivational pull of gamification with the goal of the activity, as such tuning gamification to both facilitate motivation and goal achievement |
| Contextual characteristics | **#8 Create a need-supporting context** |
| | In order to support the user's basic psychological needs, the gamified system should be implemented in a setting that is perceived as open and supporting as opposed to controlling |
| Individual characteristics | **#9 Make the system flexible** |
| | To account for personal differences, the gamified system should be flexible and adaptable in order to comply with the users' personal needs and preferences |

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# Part VIII
# Assessment of Serious Games

# Chapter 23
# Factors Associated with Player Satisfaction and Educational Value of Serious Games

**Andrew Sean Wilson, Chloe Broadbent, Brandon McGrath, and Julie Prescott**

**Abstract** Computer games are well-established forms of entertainment which have been shown to promote the development of important cognitive skills. This has also seen their evolution into games supporting training and education, known as serious games. In order to investigate those factors that would be important when developing these types of games, we conducted a 2-year study on undergraduate game development students. Seventy-four students participated in the study. They were asked for their views on three web-based serious games (Cancer Game, Darfur is Dying and Elude). A series of study questionnaires were used to collect data on their playing experience, satisfaction with the games and how well they acquired subject-specific knowledge after playing them. The students' views on the games' entertainment and educational value were mixed. Two games (Cancer Game and Darfur is Dying) were able to increase players' knowledge as a result of playing them but to differing extents. Suggested improvements to the games focused on providing more appropriate background information on the subject within the game and giving the player better feedback on how to play it. When the results were compared to existing heuristics on game development improvements to the design of the game interface, game mechanics and game playability were identified. The need to incorporate learning outcomes into the games and that they be outcome based is also important pedagogical factors. In this initial study, we have suggested a series of heuristics which the authors believe will be important to developers of serious games.

**Keywords** Serious games • Heuristics • Usability • Play • Education

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## 23.1 Computer Games

Computer games have been identified as being able to develop important skills, for example, improving perception (both attentional and visual), cognition and behaviour as well as affective and motivational status (Connolly et al. 2012). The challenge to developing these types of games is balancing both the entertainment and educational values. Some of the educational design strategies that have been used include constructivist-, experiential- and discovery-based learning, as well as situated cognition (Kebritchi and Hirumi 2008). Enjoyment, happiness and intention to use are considered to be important factors for playing these types of games and are also needed for increased learning performance (Giannakos 2013). By using appropriate learning outcomes, interest in the subject being taught within the game can be increased. This can lead to improved performance in tests, and it helps to support the transfer of acquired knowledge and skills into the real world. Reducing the amount of time it takes to teach a subject and lowering the overall teaching costs are considered to be effective benefits associated with using serious games (All et al. 2015).

There are several excellent texts on how to make games for entertainment (Rollings and Adams 2003; Fullerton et al. 2004; Braithwaite and Shreiber 2008; Schell 2008). These authors' recommendations revolve around identifying important aspects and constituent components of existing games and then subsequently proposing how they could be used to develop new ones. Design patterns have also been suggested as one way in which games could be developed (Björk and Holopainen 2005). These authors propose that by combining existing game scenarios or mechanics in different ways, new games can be produced. Despite information being available on how to develop games, there is less information on how to develop serious games. Research often focuses on their evaluation as an educational medium rather than the processes used to make them (Kebritchi and Hirumi 2008; All et al. 2015).

Reducing the possibility for unexpected events that can result in the failure of a system is important in any software development. Usability engineering is a range of techniques that put the user at the centre of the software design process (Nielsen 1993). Similarly the involvement of the players in the development of games can help to identify bugs, understand their experiences and what works within the game and what does not. Even with extensive play testing, it cannot be guaranteed that the game will be a success. Heuristics are another way of guiding the development of systems. The principle relies on the use of expert knowledge to construct processes or 'rules of thumb' for their development. This approach has also been investigated for use in game development (Federoff 2002; Desurvire et al. 2004; Pinelle et al. 2008; Desuvire and Wiberg 2009).

In a case study by Federoff (2002), ten usability heuristics, as proposed by Nielsen (1993), were compared to practices being used in the development of a game at a professional studio. As a result three areas were identified which include heuristics for game interfaces, game mechanics and game playability. In their studies Desurvire et al. (2004) propose a model called Heuristic Evaluation for Playability (HEP). They looked at four components of games which included gameplay, game story, game mechanics and game usability. Gameplay encompasses the challenges that the player must overcome in order to win the game. The story comprises the characters and plot, whereas the game mechanics determine the components of activities and actions that make up the game. Game usability defines how well the user can successfully interact with it. The study was conducted on a new game being developed by the authors. They found that HEP proved effective in identifying playability issues relating to both game story and game usability. They initially concluded that HEP was useful in early game design and best suited to finding known general issues that can occur in the early development phases using either prototypes or a mock-up of a game. Subsequent studies identified that HEP was only useful in limited circumstances leading to the proposal of a model of Heuristics of Playability (PLAY) (Desuvire and Wiberg 2009). This model was developed and tested on a series of games including real-time strategy, action and adventure as well as first-person shooters. The premise of the work was to develop a broad list of heuristics that could be used to form the foundations for development or modification of specific games. From their work Desuvire and Wiberg (2009) identified that designing games was as much an art as a science. Pinelle et al. (2008) developed their heuristics by analyzing reviews of 108 PC games from a popular gaming website. The research led them to argue that game usability should address issues of entertainment, engagement and storyline given that both artistic and technical issues are related. As a result of reviewing the literature on game development heuristics, Koeffel et al. (2009) identified 29 potential components that could be applied to the evaluation of a computer game. They postulated that the more usability issues that are found during a heuristic evaluation, the less likely that the user will get a poor experience. By applying their heuristics to five computer games, they identified a positive relationship between problems within the game and player ratings given to it on the metacritic.com website. The recommendations found in these studies (Federoff 2002; Desurvire et al. 2004; Pinelle et al. 2008; Desuvire and Wiberg 2009; Koeffel et al. 2009) are varied, but there are some aspect that are common to each of them which relate to game interface, game mechanics and game playability. These are summarized in Table 23.1.

Heuristics have also been recommended in the development of serious games; however there are only limited studies in this area. Omar and Jafaar (2010) focus on five aspects which include interface, pedagogy, and multimedia, content and playability. In terms of the educational value, they recommend games have both clear goals and learning objectives. The activities within the game should be engaging too. Other important aspects include that the game should facilitate self-directed learning, be a medium for active participation and performance should be outcome based. Despite these recommendations, their paper only focused on the theoretical side to developing serious games as they did not test their suggestions on any actual games.

**Table 23.1** Summary of common heuristics associated with developing games

| Category | Item |
|---|---|
| Game interface | Controls should be customizable |
| | The user interface should be customizable |
| | There should be appropriate mechanisms in both visual and auditory form which can provide feedback to the player |
| | The player's game world view should be clear and unobstructed |
| | A player should always be able to identify their score/status in the game |
| Game mechanics | The learning curve of the game should not be too steep |
| | The game should be responsive to the particular player's needs |
| | The game should provide meaningful feedback |
| Game playability | The artificial intelligence should be functional |
| | The player should be able to easily navigate the game world |
| | Provide clear goals, present overriding goal early as well as short-term goals throughout play |
| | Challenges, strategy and pace should be in balance |
| | The game should be learnable |
| | The game should be replayable |

### *23.1.1 Project Aims*

From a new or inexperienced developer's perspective, it is important to understand those factors which are associated with the successful development of a game. This can reduce the guess work involved in their development, leading to a reduction in the overall time it takes to make the game and potentially reducing the number of mistakes made during its creation. The series of studies discussed in this chapter are intended to investigate a range of usability factors associated with serious games. Three games were selected from the Games for Change website (http://www.gamesforchange.org/): 'Cancer Game', 'Darfur is Dying' and 'Elude'. All three are simple web-based games which can be played in approximately 10 min. The information about the games on the website describes the Cancer Game as being developed so that players can investigate the symptoms and causes of cancer. Through its gameplay, it challenges players to learn about good health practices. The premise of Darfur is Dying is to give the player an insight into the plight of the millions of refugees that live in the Darfur region of Sudan and the genocide that is occurring there. Elude was designed to raise the player's awareness and understanding of the issues people face when living with clinical depression. The studies were conducted during two academic years between 2013 and 2015. In this chapter the authors will:

- Describe the development of a series of questionnaires aimed at evaluating the entertainment and educational value of these serious games.
- Analyze play testers' views on the usability and their satisfaction with the games.

- Compare the authors' findings with existing heuristic models for game development as outlined in Table 23.1.
- Based upon the research, propose recommendations for developing serious games in future.

## 23.2 Methods

### *23.2.1 Participants*

A total of 74 first year undergraduate students studying BSc (Hons) Computer Games Technology at Birmingham City University (UK) participated in the study. Two separate cohorts were involved, one during the academic year 2013/2014 (n = 42) and another during 2014/2015 (n = 32).

The study was conducted during one of their scheduled 3 h classes on game design. All the students were asked to play as many of the three games as they could through to their completion and subsequently answer a questionnaire on each of the games.

The first cohort of students (2103/2014) was asked to complete a questionnaire giving their views on player experience, satisfaction and the educational value of each of the games. From the information gathered from this part of the study, the second cohort of students (2014/2015) were asked to complete three different questionnaires one for each of the games. The questions were derived from a thematic analysis of responses to the first questionnaire. They related to both general and specific usability issues and satisfaction with each of the games. They also included a pre-posttest knowledge quiz with questions relating to each game. This was used to assess their understanding of the subject matter associated with it.

### *23.2.2 Study Questionnaires*

Questionnaire 1: Player views and experience. The questions in this questionnaire were general in their scope and relevant to all the three games. They included questions on demographics of the players and their gaming habits. It also asked for their views on the perceived educational value, player satisfaction and suggested improvements for each of the games. Table 23.2 lists the questions.

Using Microsoft Excel version 2007, two of the co-authors (CB and BM) independently coded the responses to each of the questions, for each game, before exchanging the data between themselves and repeating the coding. This process was conducted a total of three times until a series of final themes were identified. Subsequently a second set of questionnaires was developed.

**Table 23.2** Questionnaire 1: Player views and experience cohort 2013/2014

| Theme | Question |
|---|---|
| Demographics | What is your age range? |
| | How often do you play games? |
| | Which game platforms do you use? |
| Questions | What was the game trying to teach you about? |
| | List three main elements that the game taught you? |
| Opinions | List four things you liked about the game. |
| | List four things you least liked about the game. |
| | Would you play the game again? |
| Ratings | Rate how enjoyable you felt playing the game was. |
| Improvements | How would you improve the gameplay? |
| | How would you improve the game to make it more educational? |

### *23.2.3 The Game-Specific Questionnaires*

Based upon the information gained from questionnaire 1, three questionnaires, one for each of the games, were developed (Tables 23.3 and 23.4). The questionnaires covered the following topics as well as game specific information:

- What did the game teach the players?
- What did they like and least like about the game?
- What improvements could be made to the gameplay?
- What improvements could be made to the educational content of the game?

The game specific questionnaires collected information on player demographics, their game playing habits as well as their views on the games' entertainment and educational value. They were also asked for their suggestions as to how to improve these aspects. These questionnaires also focused on evaluating the player's subject knowledge before and after playing each of the games. The original game developers did not include educational objectives or measures of knowledge acquisition with their games. Therefore a series of pre- and posttest questions were created for this purpose which was also based upon the themes identified from questionnaire 1. The post-gameplay questionnaire also asked participants where they had found the answers to the questions, for example, by playing the game, reading content associated with it or looking up information on the Internet. Table 23.3 shows the range of questions asked for each of the games, whereas Table 23.4 lists the specific pre- and posttest questions asked for each game.

**Table 23.3** Generic questions in the game-specific questionnaire 2014/2015

| Theme | Questions |
|---|---|
| Demographics | What is your age range? |
| | How often do you play games? |
| | Which game platforms do you use? |
| Opinions | Where did you find most of the information to answer the questions? |
| Ratings | How well did you feel that the game raised your awareness and gave you information about the subject? |
| | Overall how would you rate the game? |
| | How would you rate the graphical style of the game? |
| | How would you rate the sound in the game? |
| | How good was the information and feedback that was given to you whilst playing the game? |
| | How fun was the game? |
| | How difficult was the game to play? |
| Improvements | What could be done to improve the game? |
| | What could be done to improve the education experience of the game? |

**Table 23.4** Questions in the game specific questionnaire 2014/2015

| Game | Questions |
|---|---|
| Darfur | What is happening in Darfur? |
| | What country is Darfur in? |
| | Approximately how many refugees do you think are in the Darfur region? |
| | Who are the people in Darfur in conflict with? |
| | What roles do women and children play in Darfurian society? |
| | In Darfurian society what risks do people face? |
| | What risks to their homes and possessions do they face? |
| | What are the most precious resources to Darfurians? |
| | How do they use this resource? |
| | What charities are raising awareness of issues in Darfur? |
| Elude | How much does depression affect people's lives? |
| | List four ways depression can affect an individual. |
| | List three mood states that can be associated with people living with depression. |
| | List three ways depression can be positively overcome. |
| Cancer game | Who can cancer affect? |
| | How have you previously learnt about or found information about cancer? |
| | List four parts of the body that cancer can affect. |
| | List four things that you could do to reduce your risk of getting cancer. |
| | What's the end motto of the game? |

## 23.3 Results

### *23.3.1 Demographic*

The participants were aged between 18 and 25 years old and predominantly male (93%). Fifty-three respondents played games on a daily basis, 15 a few times a week, 3 played only a few times a month and 1 only played occasionally.

### *23.3.2 Evaluation of Serious Games for Playability and Educational Content*

The following sets of results were derived from the initial 2013/2014 study using questionnaire 1. Each student could provide multiple responses to items, for example, what the game taught them, as well as what they liked and least liked about it. The data is presented as the number of responses made to each theme. Similar responses made by the same individual were only counted as one response.

#### 23.3.2.1 Cancer Game

Thirty-nine students responded to the questionnaire. When asked what they thought the Cancer Game taught them, four themes were identified. These were how to avoid cancer ($n = 20$), followed by how to live/eat healthily ($n = 12$), learning about the human body ($n = 5$) and the effects of cancer and how it spreads ($n = 3$). When asked what they liked about the game, responses included the game's aesthetics ($n = 17$), its mechanics ($n = 11$), the educational aspect ($n = 9$) and the concept ($n = 6$). Seven themes emerged when asked what they least liked about the game. These were that the game was confusing ($n = 22$), the visuals of the game were not very good ($n = 10$), the time it took to load the game ($n = 9$), it was boring ($n = 7$), it lacked relevance ($n = 6$), it was too linear ($n = 5$) and lacked feedback ($n = 4$). When asked how to improve the gameplay, suggestions included addition of more information and hints within the game ($n = 14$), less point and click ($n = 5$) as well as better feedback and visuals ($n = 4$). Improvements to the educational aspect included more facts about cancer ($n = 13$) as well as better information and feedback within the game ($n = 8$). Indicative suggestions for improvements to the gameplay and educational value include:

> "*The controls could have been done a little better so that the player knows what to do*."
> "*Add some more interactivity, some movement instead of point and click*."
> "*I think more hints provided throughout the game would have made the game more educational*."
> "*Give the player hints or at least tell them what to do on each level*."
> "*Once a level is completed have an explanation of what type of cancer and ways of preventing it*."

"*The game assumes you are aware of everything about cancer. It should inform you about the lack of a cure and the research into cancer.*"
"*actually indicate what the player is doing as they play through.*"
"*Put captions for each action that player does explaining what is happening. The gameplay can't explain it all.*"

#### 23.3.2.2 Darfur Is Dying

Forty-two students responded to the questionnaire. When asked what they thought, Darfur is Dying taught them three themes emerged. These related to the living conditions the citizens experience (n = 31), the conflict that exists between citizens and the militia (n = 11), as well as the need for foreign support and medicine (n = 4). When asked what they liked about the game, four themes were identified. These included raising awareness of the situation that exists in Darfur (n = 19), the mechanics of the gameplay (n = 19), the visual aesthetics of the game (n = 9) and its difficulty and intensity (n = 7). What they least liked about the game were the mechanics of the game (n = 22), that the game was boring and repetitive (n = 11), that the game was unclear and confusing (n = 10) and the visual aesthetics of the game (n = 9). The data showed that there was contradictory information regarding the responses for both liking and disliking both the game mechanics and its aesthetics. When asked how to improve the gameplay, suggestions included improving the controls and instructions (n = 11), add more challenges and their variety (n = 11) and improve the graphics (n = 6). Improvements to the educational aspect included adding explanatory cut scenes or animation (n = 6) in order to provide more background information about the crisis in Darfur (n = 6). Suggestions to improve the gameplay and educational content included:

"*Provide more information to the users on how to play.*"
"*Provide more user feedback, reduce large blocks of text and find more immersive ways of getting information across.*"
"*Make foraging more skill based, make camp construction easier to understand, make story more integral and less wall of text.*"
"*Give a different graphical style as I didn't quite feel the threats with the cartoony style.*"
"*Include more facts about the crisis to make people more aware.*"
"*Elucidate on how this is not only happening in one country but others too.* "
"*Add more consequences, give stats at the end of the game e.g. starvation.*"
"*Add videos to show what is really happening in Darfur.*"
"*Add extra option to the menu – questionnaire/quiz. Help the user make sure they have learnt something.*"
"*Make it more visceral. Less text more showing the events of what happened in the region.*"

#### 23.3.2.3 Elude

Forty-two students responded to the questionnaire. Analysis of their responses to what they thought the game taught them revolved around raising awareness of depression (n = 18) and understanding that mood changes can occur in this condition (n = 9). The respondents liked the game's aesthetics (n = 27), its game mechanics (n = 24), the awareness raising element of the game (n = 10) and its simplicity (n = 6). What respondents least liked were that they found it boring and repetitive (n = 15), its mechanics (n = 8) and the outcome of the game (n = 4) and that it was unclear what to do and too hard (n = 4). Similarly to Darfur is Dying, items such as game mechanics were cited as being both liked and disliked by the respondents. Overall improvement in the actual gameplay (n = 11) were suggestions as to how to improve the game. More background information to clinical depression would improve the educational value (n = 29). Suggestions to improve the gameplay and educational content included:

"*Provide a map to tell players where they are and where the objects are in the level*."
"*A way to trace how well you are doing in the game*."
"*Have the environment slowly progress. An explanation of the purpose of both birds and pulse power*."
"*Add an ending, add more objectives, have a more significant progression.*"
"*Clear objectives, better instructions*."
"*Facts about depression. Explain how depression affects people. Explain the stages of depression*."
"*Make story slightly more obvious and give clear indications as to the objective of the game*."
"*State ways of how to avoid depression and the bad effects of depression*."

### *23.3.3 Rating and Replayability of the Games*

When the respondents were asked whether they would play these games again, of the 39 who played the Cancer Game, only three said they would. Of the 42 who played Darfur is Dying and Elude, only five said they would replay the former and ten the latter. Participants were asked to rate each game from 1 poor to 10 excellent. Table 23.5 shows the responses to each game. None of the games scored above 8, with the cancer game not scoring more than 7. If we calculate the number of ratings above 5 for each game, Darfur is Dying faired the best with 20 responses, followed by Elude (n = 17) and the cancer game (n = 12).

**Table 23.5** Player rating of each game

| | | Overall rating of game | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of responses | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Elude | 42 | 5 | 7 | 9 | 4 | 1 | 6 | 9 | 1 | 0 | 0 |
| Cancer game | 38 | 8 | 9 | 5 | 4 | 6 | 2 | 4 | 0 | 0 | 0 |
| Darfur is dying | 40 | 2 | 5 | 8 | 5 | 12 | 7 | 0 | 1 | 0 | 0 |

**Table 23.6** Number of correct answers to game-specific questions

| | | Number of correct answers to quiz | |
|---|---|---|---|
| Game | Number of responses | Pregame | Postgame |
| Cancer game | 32 | 7.1 ± 1.61 | 8.6 ± 1.16 *** |
| Darfur is dying | 31 | 3.9 ± 3.23 | 11.2 ± 2.33 *** |
| Elude | 28 | 3.6 ± 1.13 | 3.3 ± 1.62 |

Data represented as mean ± s.d. Wilcoxon signed rank test ***$p<0.001$

## *23.3.4 Knowledge Quiz*

The pre-posttest knowledge quiz was conducted on 32 students in the academic year 2014/2015. Data is presented as mean ± s.d. analysis was conducted with the Wilcoxon signed rank test using the MaxStatLite statistical software package. Table 23.6 shows that students increased their subject-specific knowledge after engaging with the games Darfur is Dying and Cancer Game, but not the Elude game.

### 23.3.4.1 Cancer Game

Thirty-two students answered the quiz. Mean correct responses to questions prior to playing the game were 7.1 ± 1.61 and after 8.6 ± 1.16. Twenty-five students answered the questions as a result of just playing the game, whereas seven answered questions as a result of reading the accompanying text to the game, using the Internet or combinations of these. Of the 25 that just played the game, the mean correct responses to questions before playing were 7.2 ± 1.60 and after 8.5 ± 1.1 ($p < 0.001$).

### 23.3.4.2 Darfur Is Dying

Thirty-one students answered the quiz. Mean correct responses to questions prior to playing the game were 3.9 ± 3.23 and after 11.2 ± 2.33. Fifteen students answered the questions as a result of just playing the game, whereas 16 answered questions as a result of reading the accompanying text to the game, using the Internet or combinations of these. Of the 15 that just played the game, the mean correct responses to questions before playing were 3.5 ± 3.23 and after 10.9 ± 2.64 ($p < 0.001$).

### 23.3.4.3 Elude

Twenty-eight students answered the quiz. Mean correct responses to questions prior to playing the game were 3.6 ± 1.13 and after 3.3 ± 1.62. Fourteen students answered the questions as a result of just playing the game, whereas 12 answered questions as a result of reading the accompanying text to the game, using the Internet or combinations of these. Of the 14 that just played the game, the mean correct responses to questions before playing were $3.6 \pm 1.34$ and after $3.2 \pm 1.63$.

### *23.3.5 Player Satisfaction*

The second cohort of students was also asked questions around seven themes that had emerged from questionnaire 1. These questions related to the level of awareness and subject information that the game gave the player, rating of both the games' graphical style and sound quality as well as the quality of information and feedback given to the player and how fun the game was and the level of difficulty associated with each of the games. Players were also asked to give an overall rating of the game. Ratings for all of these questions were from $-5$ (very bad) to $+5$ (very good). Table 23.7 shows the percentage of responses that were either in the negative or positive ranges for each of the questions, together with a calculated difference between the two values. All of the games were rated more positively for each of the questions except the quality of the sound in Darfur is Dying and the level of fun in Cancer Game which were rated more negatively. Some of the items were less differentiated than others with negative and positive opinions being closer to each other. This included for the level of awareness of the subject matter in Elude, the graphical style of Darfur is Dying, the level of information and feedback in the Cancer Game and Elude, the level of fun in the Cancer Game and Darfur is Dying, as well as the difficulty level of Cancer Game.

The second cohort of students was also asked about their views on how to improve each of the games, in terms of gameplay and educational value. Suggestions for the Cancer Game included improving feedback and information both for how to play it ($n = 12$) and for providing education ($n = 15$). This was a similar response in Darfur is Dying with 12 individual responses citing more feedback and information being needed in both these aspects. Clearer gameplay objectives ($n = 23$) and feedback on issues relating to depression ($n = 18$) were cited as possible improvements to Elude.

Based upon the calculated difference between the positive and negative values, the order of satisfaction with the Cancer Game was graphical style, awareness, overall rating of the game, its sound, the level of difficulty, the level of feedback and how fun it is. With Darfur is Dying, the order was awareness, overall rating of the game, level of feedback, level of difficulty, its graphical style, how fun it is and its sound. With Elude the order was graphical style, its overall rating, difficulty level, its sound, how fun it is, the level of feedback and how well it raised awareness of the subject matter.

**Table 23.7** Comparative analysis of player perceptions and satisfaction with each game

| | Cancer game | | | Darfur is dying | | | Elude | | |
|---|---|---|---|---|---|---|---|---|---|
| | −ve | +ve | Difference | −ve | +ve | Difference | −ve | +ve | Difference |
| How well did you feel that the game raised your awareness and gave you information about the subject? | 22.6 | 67.7 | 45.1 | 9.7 | 90.3 | 80.6 | 36.3 | 51.5 | 15.2 |
| How would you rate the graphical style of the game? | 22.6 | 74.2 | 51.6 | 41.9 | 58.1 | 16.2 | 6.1 | 93.9 | 87.8 |
| How would you rate the sound in the game? | 6.5 | 32.3 | 25.8 | 29.0 | 19.4 | −9.6 | 6.1 | 48.5 | 42.4 |
| Overall how would you rate the game? | 29.0 | 67.7 | 38.7 | 16.1 | 83.9 | 67.8 | 3.0 | 87.9 | 84.9 |
| Quality of Information and Feedback. | 38.9 | 51.7 | 12.8 | 12.9 | 74.2 | 61.3 | 32.4 | 52.9 | 20.5 |
| Fun. | 48.3 | 32.3 | −16 | 35.4 | 48.4 | 13.0 | 27.2 | 66.7 | 39.5 |
| Difficulty. | 32.3 | 51.7 | 19.4 | 29.0 | 54.8 | 25.8 | 9.1 | 72.3 | 63.2 |

Data is presented as the percentage of number of respondents (Cancer Game n = 31, Darfur is Dying n = 31 and Elude n = 32) that rated the item as being either negative or positive. Responses that were given a zero rating have not been included. The difference between the positive and negative results has also been calculated

### *23.3.6 Comparison with Heuristics*

Based upon the information gathered in this study and playing the games, the authors rated them for how well they felt they achieved the common heuristics which were identified in Table 23.1. The games were rated as to whether the items were not present, there was limited implementation or the implementations were either acceptable, good or excellent (Tables 23.8 and 23.9).

Of all three games, the Cancer Game lacked many of these key attributes, or there was only limited implementation. Darfur is Dying and Elude had more items that had an acceptable or a good level of implementation; however none of the games were considered excellent given the responses that were made by the players during their analysis of them.

**Table 23.8** Comparison of each game with common heuristic associated with game development

| Category | Item | Cancer game | Darfur is dying | Elude |
|---|---|---|---|---|
| Game interface | Controls should be customizable | NP | NP | NP |
| | The user interface should be customizable | NP | NP | NP |
| | There should be appropriate mechanisms in both visual and auditory form which can provide feedback to the player | L | G | A |
| | The player's game world view should be clear and unobstructed | G | G | G |
| | A player should always be able to identify their score/status in the game | NP | A | NP |
| Game mechanics | The learning curve of the game should not be too steep | L | A | G |
| | The game should be responsive to the particular player's needs | L | G | G |
| | The game should provide meaningful feedback | L | G | L |

*NP* not present, *L* limited, *A* acceptable, *G* good and *E* excellent

**Table 23.9** Comparison of each game with common heuristic associated with game development

| Category | Item | Cancer game | Darfur is dying | Elude |
|---|---|---|---|---|
| Game playability | The artificial intelligence should be functional | NP | A | NP |
| | The player should be able to easily navigate the game world | L | G | G |
| | Provide clear goals, present overriding goal early as well as short-term goals throughout play | L | G | A |
| | Challenges, strategy and pace should be in balance | L | G | G |
| | The game should be learnable | L | G | G |
| | The game should be replayable | L | L | G |

*NP* not present, *L* limited, *A* acceptable, *G* good and *E* excellent

## 23.4 Discussion

The three games evaluated in this chapter were originally created to raise awareness of particular issues such as cancer, mental health (depression) and genocide. The authors were interested in how each of them achieved these objectives by assessing both players views and measuring educational content. In the first section of this discussion, the authors will give a brief overview of the each of the games.

### 23.4.1 Review of the Games

The Cancer Game requires the player to navigate different levels representing the lungs, liver, stomach and intestine. Within each organ there are a series of activities associated with cancer prevention and suggestions for a healthy eating and lifestyle. For example, in the lung level, the player needs to select drugs to defeat the 'enemy' cancer, before clearing a path to collect a key which allows the player to leave that level. In the liver the character has to match a series of icons of healthy drinks in order to stop the flow of alcohol into a machine which represents the liver. By using a drug, the player kills the cancer allowing them to collect another key so they can then move to the next level. Similar activities occur in the stomach and intestine levels; each time the player has to defeat the 'enemy' cancer by using drugs and progress through the level by selecting healthy foods to help them.

Darfur is Dying describes itself as a narrative-based simulation. There are two main activities within the game. The first one involves foraging for water, and the second one involves using the water to manage resources within their camp. At the start of the game, you are required to select a Darfurian citizen to forage for water. The character has to reach the water well avoiding being captured by the militia. The character is able to run and hide behind objects whilst 'enemy' characters chase them in their vehicles. Feedback in the form of a dialogue box indicates to the player the distance and location of the well. Once the player has collected the water, they have to navigate back to their village without being intercepted by the pursuing enemy militia. The game mechanics in this section provides the player with elements of both risk and challenge. If the player character is caught by the militia, this section of the game ends, and information is presented on the screen highlighting the types of risk the player's character may encounter in Darfur. The player can then move onto the next section of the game which is managing the Darfurian camp. This requires the player to continue to collect water so that they can maintain the camp's gardens in order to grow food and use the water to make bricks so they can build shelters. In combination with visits to the medical centre, these activities are needed to keep the player healthy so that they can subsequently maintain the camp as long as they can whilst avoiding attacks from the militia.

Elude is a platform-based game with simple game mechanics that requires the player to take control of a character, moving and jumping onto tree branches in order to navigate the game world (forest). A puzzle element involves the player trying to find the best route through these trees in order to reach the sky and then ascend higher by jumping on game objects such as flowers and leaves. If the player moves or jumps inaccurately, they can miss these items and fall back to their starting point, the forest floor. This gives the game a strong element of skill, challenge and risk.

### 23.4.2 Comparison of Player Views of the Three Games

Players felt that Darfur is Dying was better at raising awareness when compared to the Cancer Game or Elude, and as a result of playing, it produced the largest overall increase in knowledge acquisition. However the players stated that the game could be further improved by supplying more background information. Elude was rated higher than the other games for several factors which included its graphical and audio style. It was also rated higher than the other games for its mechanics, level of fun and how challenging it was to play, as well as scoring high in its overall rating as a game and the one players' would potentially play again. Players stated that they felt they were more aware of the issues associated with depression although this was not demonstrated by any significant change in their scores in the knowledge quiz.

### 23.4.3 Comparison to Published Heuristics

The next section discusses how the three games reflect those heuristics that were previously summarized in Table 23.1. As these heuristics were originally developed to assess commercial PC and video games, rather than serious games, we have also included discussion of how the games meet the education requirements (clear learning goals, learning outcomes and be outcome based) as proposed by Omar and Jafaar 2010; Giannakos 2013.

***Make the game fun to play, easy to learn with no repetitive or boring tasks. Provide a variety of challenges to maintain player interest and enhance the game's replay-ability***

By their nature games should be fun to play and engaging otherwise players will quickly lose interest and stop playing them which also has obvious consequences if the game is intended to be educational. Of the three games evaluated, both Elude and Darfur is Dying were considered to be relatively more fun to play than the Cancer Game with Elude being the one that players rated highest. Elude could have been considered to be the more fun for the players and initially easy to learn because its mechanics are based upon a familiar and well-established genre (platformer). It also had more challenges and risks in its gameplay, requiring the player to develop their skills in order to proceed through the game. Darfur is Dying also used risk and challenges in its gameplay; however this was more prominent in the foraging for water section rather than in the camp management. The players felt this part of the game to be unclear and confusing leading them to feel that the game was a little boring and repetitive. The Cancer Game was also criticized for lacking fun. The downside being that many of the player actions are down to 'trial and error' as a result of them having to perform random ‘point and click’ actions in order to interact with the game and game objects. The sequence of activities required to complete each level is always the same so there is no variety or challenge for the player, subsequently the players felt this game to be boring and lacked relevance. By adding more variety of tasks, more challenges and risks to the games players are required to develop their skills in order to master them. This could help reduce repetition, make the game less boring and help to encourage replayability.

***Make the game aesthetically pleasing***

The graphical and visual style of a game can be very important to players. However the responses of the players showed that opinion can be divided even on the same game. This is not unsurprising given that games are considered forms of art and perceptions of what constitutes appealing graphics to one person can be different to others. Of the three games, Elude was rated highest by the players for its graphical and audio style which may reflect their higher quality. Darfur is Dying was criticized by one player feeling that the threats within the game were lessened as a result of the cartoon style of graphics. Players’ views on the visual and audio style of the Cancer Game were mixed although these were rated lowest of all the three games.

***Use different graphical, audio and visual channels to promote immersion; provide feedback to users on how to play the game and as a way of supplying important background information on the educational topic. Have clear meaningful goals and objectives within the game which are supported by hints and immediate feedback which support the player if they get stuck or confused***

Poor quality of feedback was a recurrent theme for many players of the games. Criticism was focused on the limited information available on how to play them as well as poor background information on the subject matter. Of the three games, Darfur is Dying had the most information within it. This was in the form of ‘pop-up’ dialogue boxes that give textual information about the situation occurring within the region and information on the activities the player needed to perform within the game, for example, which gardens to water, prompts that medicines had arrived or attacks by the militia were imminent. However players still felt the instructions for managing the camp, and its resources were limited and sometimes confusing. Overall players suggested the need to provide alternative ways of presenting information on the situation that was occurring in Darfur, and rather than using large blocks of text, adding videos, cutscenes and animations would be more helpful. Despite this, the level of information contained within this game most probably resulted in the players’ better performance in the knowledge-based quiz. Neither Elude nor the Cancer Game provided feedback on how to play them and outside of text accompanying the game on their respective websites, any supporting information about what the game was trying to teach the players.

***Provide clear ways that players can identify their score, status, progress and achievements within the game***

Players progress within a game; their achievements and knowing whether they have won or lost are important. Only Darfur is Dying provided this type of information. Within the camp section, a graphical user interface gave the player information about the camp's status. Information included the relative levels of water and food supplies, the overall health status of the camp, the level of threat from the militia and the day number indicating the player's progress in maintaining the camps survival. Elude and the Cancer Game did not display any information to the player on their progress. The players therefore felt that this made the game more difficult to learn and how to succeed in, leading to confusion as to what the outcome and (educational) objectives of the game were.

***Ensure that the player can easily navigate the game world and environment and can customize it if required***

Frustration can often occur in games when players are not able to do what they want, get to where they want to or when the game reacts in unexpected ways. In the absence of providing tutorials and explanations, it is important to make the game as intuitive as possible to play. Darfur is Dying did make some attempt at providing the players with guides as to how to play it, for example, by selecting icons on game objects 'pop-up' menus with relevant game information were displayed. However the players still felt that these were not always as helpful as they could have been. Elude's gameplay is based upon a well-known genre with recognizable mechanics which made it initially more intuitive to play. The Cancer Game provided no guide as to how to play it leading to confused players who commented on the need to give them hints and show them what to do on each level as well as giving indications as to what the player is doing and achieving as they play through the game. The Cancer Game would have benefitted from the introduction of either a short tutorial or time-dependent feedback. In this situation players who were not engaging in particular tasks, within an appropriate time frame, would have been given some assistance early on. This could have reduced the level of frustration and confusion in not knowing what to do, rather than the players feeling that they had to rely on guess work in order to complete the game. By allowing the player to be able to customize the environment, for example, by setting the level of difficulty and relative levels of feedback, novice players can learn to play the game quickly, but it can also make it more challenging for more experienced players when that information is reduced or removed.

***Make sure the controls are appropriate to the game, where possible customizable and easy for the player to use so that they feel that they are in control of the game. Pay attention to accessibility issues; user interface and user experience when designing games especially for players who may have a disability***

Players need to interact with games, and recognizable mechanisms and conventions for input have existed for some time. For example, PC games are often controlled by using the keyboard keys WASD or the arrow keys for movement, the space bar for jumping and mouse for navigation and looking around the environment. By using this standardized approach, players can quickly learn to play the game through familiarity of action. However players may feel they are more comfortable and in control of the game by choosing alternative mechanisms. Darfur is Dying and Elude allowed players to play the game using the arrow keys, but there was no option to use the WASD keys. The Cancer Game relied solely on point and click navigation. Some players may have preferred to use game pads and controllers too. However it is acknowledged that some game development environments or gaming platforms do not always have the scope to provide a range or different types of input for the user. Inclusivity is also an important consideration when designing serious games, for example, for players who may have physical limitations or some level of disability. Players may need access to different types of input controller; players with poor visibility may need more audio feedback or the ability to adjust the layout of the screen to their particular requirements. People with hearing impairments may need to adjust sound levels or will be more reliant on visual cues for their feedback.

***If artificial intelligence is used then it should be functional***

Competition is an important element of games. This may take the form of competing against a fellow player or against the game itself. In the latter case, artificial intelligence is used to represent the opponent. High-quality reliable artificial intelligence can be difficult to achieve as its accuracy can be very dependent upon how well the game is optimized in order to work. If the game speeds up or slows down, then the artificial intelligence can become out of synchronization with the actual gameplay. Darfur is Dying was the only game to use some level of artificial intelligence. One noticeable flaw in its execution was that when the militia chased the player character, they did not always follow them allowing the player to exploit this allowing them to escape. This was only a minor issue but when implementing artificial intelligence as it must be perceived by the player to function correctly, it must be believable to the player and result in enhancing the gameplay rather than disrupting it.

***Provide learning outcomes from the beginning so players know what they are expected to learn. This should be reinforced by providing appropriate feedback and subject specific information within the game***

Serious games are intended to be educational and players are expected to learn from them. Based upon the findings of this study, each of the games did achieve the objectives but to varying extents. Based upon the player feedback, Darfur is Dying provided them with insights into the plight of the refugees that live in the Darfur region of Sudan and the genocide that is occurring there. The Cancer Game allowed players to investigate the symptoms and causes of cancer as well as learning about good health practices, but the players felt this was achieved only to a limited affect. Elude raised player's awareness of the issues people face when living with clinical depression, but this message was not always clear to the player. Of all three games, playing Darfur is Dying resulted in a significant increase in knowledge acquisition by the players. There was a small but significant increase after playing the Cancer Game and no significant change as a result of playing Elude. When the players were asked for comments on these games, they felt that the associations between the game objectives and the educational message (cancer prevention and depression) were sometimes difficult to discern.

Each of the games provided an explanation of what they were trying to achieve on their websites. This could have been further enhanced and the players' attention focused more by providing more explicit learning outcomes or objectives. These could be set at the start of the game or associated with supporting material, for example, on the game's website. The latter has more flexibility for offering alternative learning outcomes depending upon the audience or what the emphasis in learning should be given a particular teaching scenario. If the learning outcomes are based within the game, then they are fixed.

Learning should also be reinforced within the game. Darfur is Dying was the only game to do this. Feedback was provided within it by adding dialogue boxes supplying the player with additional information. Progress within the game was supported by menus and graphical user interfaces. However its approach to providing feedback was criticized by the players with too much reliance on large blocks of text which disrupted the gameplay. This resulted in suggestions for alternative ways of presenting the information, for example, incorporating video showing the plight of the Darfurians which may have also been a more powerful way of conveying the intended message.

In summary we can posit that Darfur is Dying was better at providing an educational experience owing to the greater depth of information that it contained, whereas familiar game mechanics, aesthetics, fun and difficulty, as seen in Elude, were more indicative of the 'better' game.

## 23.5 Limitations of the Work

The study was conducted on 74 first year undergraduate computer games technology students of which 68 (92%) could be considered regular gamers. We did not collect data on the number of years they had been playing games, yet the indication was that prior to the study, they would have had substantial experience of playing them and therefore would be able to provide critical and knowledgeable evaluations of the three games.

The authors' research identified that there was a lack of clear pedagogical objectives associated with the games. This meant that the authors had to create their own questionnaires. This was done through analysis of the responses from the first cohort of students based around what they thought that the game was trying to teach. Some of the games, for example, Darfur is Dying, were richer in content when compared to the two others meaning that the number of questions associated with some of the games was more limited. This may also indicate that the original design of those games did not necessarily focus as much on the educational side as they did on the game itself.

There is a range of heuristics available for designing entertainment games including for the design of the game interface, game mechanics and game playability. However these were derived from specific game types or genres. Given the dates when these studies were conducted and the fast pace of the game industry, some of their findings may no longer be relevant to more current games.

The authors' research only identified one study that was associated with the heuristic development of serious games (Omar and Jafaar 2010), which was a theoretical model which had not been tested on any actual games. However the findings of the authors' current study concur with their suggestions that serious game should have learning outcomes be outcome based. In other theoretical work on serious game development, authors stressed the importance of fun and the intention to play the game (Giannakos 2013) which we have assessed in our study. Other suggestions, for example, reducing the amount of time it takes to teach a subject and lowering the overall teaching costs (All et al. 2015) were not evaluated within the authors' study, since the focus was primarily on assessing the entertainment and educational value of each of the games.

## 23.6 Conclusion

To the authors' knowledge, this study was one of the first to conduct a holistic evaluation of both the entertainment and educational value of serious games. The findings indicate that player satisfaction is dependent upon the quality of the aesthetics and the game's perceived level of fun and its educational value as measured by the level of feedback and information that the game contains. A more effective educational experience would be dependent upon providing clearer pedagogical goals and better use of contextualized feedback and background information within the game. This study was restricted to three games which were chosen for both their simplicity and subject matter; however the initial findings form a strong basis for understanding the requirements for developing serious games in future. However further refinement and testing on other serious games will be needed to form a more comprehensive picture.

An initial framework for developing serious games is summarized in Box 23.1. This is based upon combining the work in this study with the core heuristics identified from previous research (Federoff 2002; Desurvire et al. 2004; Pinelle et al. 2008; Desuvire and Wiberg 2009; Koeffel et al. 2009) and the proposals made for heuristics for serious games (Omar and Jafaar 2010; Giannakos 2013).

**Box 23.1: Recommendations for developing serious games:**

- *Make the game fun to play, easy to learn with no repetitive or boring tasks.*
- *Provide a variety of challenges to maintain player interest and enhance the game's replayability.*
- *Make the game aesthetically pleasing using high-quality audio and graphics.*
- *Use different graphical, audio and visual channels to promote immersion; provide feedback to users on how to play the game and as a way of supplying important background information on the educational topic.*
- *Have clear meaningful goals and objectives within the game which are supported by hints and immediate feedback which support the player if they get stuck or confused.*
- *Provide clear ways that players can identify their score, status, progress and achievements within the game as well have clear win/lose conditions.*
- *Ensure that the player can easily navigate the game world and environment and can customize it to their needs if required.*
- *Make sure the controls are appropriate to the game, where possible customizable and easy for the player to use, so that they feel that they are in control of the game.*
- *Pay attention to accessibility issues, user interface and user experience when designing games especially for players who may have a disability.*
- *If artificial intelligence is used, then it should be functional enhancing the game rather than disrupting it.*
- *Provide learning outcomes from the beginning so players know what they are expected to learn from the game.*
- *Learning should be reinforced by providing appropriate feedback and subject-specific information within the game. Provide alternative ways of presenting that information, for example, video or animations.*

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# Chapter 24
# Learning Analytics as an Assessment Tool in Serious Games: A Review of Literature

**Min Liu, Jina Kang, Sa Liu, Wenting Zou, and Jeff Hodson**

**Abstract** The purpose of this chapter is to conduct a systematic review of research on studies using analytics (particularly in-game data such as logs) in serious games (SG) to understand what research has been conducted and what research evidences there are in using analytics in SG to support teaching and learning. The findings of this review showed learner performance and game design strategies were the two most common researched topics. Other topics included motivation and engagement, student behavior, problem solving, learner progress trajectories, and student collaboration. In addressing students' learning performance, more studies reported that SG had a positive impact on learning; and many highlighted the importance of game design. Some of the studies reviewed also indicated the challenges for researchers to use in-game dynamic data as a research measure. Several trends are identified and implications for future research are discussed.

**Keywords** Serious games • Learning analytics • In-game log data • Literature review • Analytics as an assessment tool

## 24.1 Introduction

Video game is a multibillion dollar industry. Close to 50% of American adults ever play video games (Duggan 2015), and about 60% of K-12 students reported playing video games daily (Rideout et al. 2010). Given this prevalent form of entertainment, educators are interested in exploring using serious games (SG)—games designed to facilitate learning—to support teaching and learning of discipline knowledge and critical thinking skills.

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Much research has been published on various aspects of SG. Various research methodologies have been employed. A unique aspect of SG is dynamic and just-in-time data can be captured in this digital environment as a useful form of data sources to understand how students use the game in relation to other factors under investigation. Using analytics in SG can reveal the process of performance improvement via in-game instructional resources (van Barneveld et al. 2012). Usage patterns can contribute to the understanding of learning models that can then be utilized to predict student knowledge-building trajectories through the categorization of levels of performance, engagement, and resource-processing sequences (US Department of Education, Office of Educational Technology 2012). Yet, capturing and utilizing such in-game data for research has been a challenge. Given the recent advancement of technologies and the emerging field of learning analytics, new opportunities are available for researchers in the SG field to investigate the use of the enormous volume of dynamic data generated by SG. To help researchers interested in using analytics to gain insights that can enable the design and validation of pedagogical scaffolding, a review of literature is much needed.

### *24.1.1 Purpose of the Study and Research Questions*

The purpose of this chapter is to conduct a systematic review of research on studies using analytics (particularly in-game data such as logs) in SG to understand what research has been conducted and what research evidences there are in using analytics in SG to support teaching and learning. The following research questions guided this review:

1. What issues have researchers been investigating on using learning analytics in SG?
2. What research evidences are there in using analytics to support teaching and learning through SG?
3. What techniques have been used to investigate analytics in SG?
4. What challenges have researchers identified in using analytics for SG?
5. Are there any trends as shown by the research studies reviewed?

## 24.2 Method

We reviewed research studies published within a 10-year time frame—2005 to present—and are *data-based* only, not including descriptions of projects or articles merely discussing benefits and/or challenges of learning analytics in SG. A literature review on this emerging topic should provide much needed perspective to researchers and practitioners in understanding the current state of SG research and provide a foundation for performing cutting-edge research on the topic.

### 24.2.1 Article Selection Criteria

We followed the selection criteria used in our two previous literature reviews (Liu et al. 2013, 2014) but with the focus of analytics in SG as the topic of this study. The following four criteria guided our selection:

1. Research published in refereed journals only (not including conference proceedings or book chapters).
2. Research that are data-based, not including descriptions of projects or articles merely discussing benefits and/or limitations.
3. Research published between 2005 and February 2016 when the analysis of this review began.
4. As a critical consideration for this review, the study included in-game data (e.g., game-feature use logs, game-chat logs) as one of the data sources and excluded those studies that did not include log data.

Using these criteria, we went through several steps in selecting and verifying our data sources—articles for inclusion in the review. First, we went through a group of articles ($n = 86$) we have been collecting on the topic as we have been engaged in doing research on learning analytics in SG for the past several years (Liu et al. 2015, 2016). We then reviewed the references of each of these articles and created a list of journals ($n = 27$) in which possible relevant articles were published. We then checked each of these journals to ensure the journal is refereed according to its description and publishes research on the topic of this review and excluded journals that do not meet this criterion. This step resulted in nine journals. The research team then browsed the abstracts of the publications from 2005 to Feb. 2016 in each of these nine journals to find any articles that possibly met the four criteria mentioned above. After this process, a total of 50 articles were selected. These 50 articles became the pool of articles for further consideration.

At this point, the research team read each of these 50 articles more in depth to decide if the study actually met the four criteria. This step eliminated those that appeared to be given the abstract, but actually did not meet our criteria. Each inclusion or elimination was verified by a second researcher to ensure there was a consensus for the selection. This step further eliminated several articles. After this long careful and deliberative process of finding, checking, selecting, and verifying, a total of 22 articles were included in our final review (see Table 24.1). Figure 24.1 illustrates our selection process.

### 24.2.2 Analysis

Hart's (1999) suggestion of finding a reasonable "classification" in conducting literature review to identify the connections and contrasts among the research articles guided this review. We used a constant comparative iterative approach

**Table 24.1** Summary table of each article reviewed

| Authors (Year) | Journal | Data source | Grade level[a] | Topics |
|---|---|---|---|---|
| Kiili (2005) | *The Internet and Higher Education* | Log data, questionnaire, interview, posttest | HE | Engagement, student behavior |
| Hämäläinen (2008) | *Computers & Education* | Videotaping, audio recording, log data | TR | Learner progress, game design strategies, student collaboration |
| Burton and Martin (2010) | *Journal of Educational Computing Research* | Log data, survey, interview | HE | Student performance, student collaboration |
| Liao et al. (2011) | *Journal of Computer Assisted Learning* | Log data, field observation, interviews, pre- and posttest | ES | Game design strategies, motivation |
| Liu et al. (2011) | *Computers & Education* | Log data, survey | HE | Problem solving |
| Spires et al. (2011) | *Journal of Educational Computing Research* | Log data, pre- and posttest | MS | Student performance |
| Sun et al. (2011) | *Computers & Education* | Log data | ES | Game design strategies, problem solving |
| Hou (2012) | *Computers & Education* | Log data | ML | Student behavior |
| Kerr and Chung (2012) | *Journal of Educational Data Mining* | Log data | MS | Student performance, problem solving |
| Klopfer et al. (2012) | *Journal of Computer Assisted Learning* | Log data, pre- and post-survey | ES | Game design strategies, motivation |
| Forsyth et al. (2013) | *Journal of Educational Data Mining* | Log data, cognitive discourse (feedback, questions, etc.) | HE | Motivation |
| Loh and Sheng (2013) | *Education and Information Technologies* | Log data | HE | Student performance |
| Loh and Sheng (2014) | *Computers in Human Behavior* | Log data | HE | Student performance |
| Cagiltay et al. (2015) | *Computers & Education* | Log data, pre- and posttest, survey | HE | Game design strategies, motivation, student performance |
| Cheng et al. (2015) | *Computers & Education* | Log data, concept learning assessment | MS | Student performance, student behavior |

(continued)

**Table 24.1** (continued)

| Authors (Year) | Journal | Data source | Grade level[a] | Topics |
|---|---|---|---|---|
| Gauthier et al. (2015) | *Computers & Education* | Log data, pre- and posttest | HE | Game design strategies, motivation, student performance, problem solving |
| Kerr (2015) | *Journal of Educational Data Mining* | Log data | MS | Game design strategies |
| Liu et al. (2015) | *Technology, Knowledge and Learning* | Log data, pre- and posttest, survey | MS | Student performance, student behavior |
| Loh et al. (2015) | *Computers in Human Behavior* | Log data | HE | Student performance |
| Minović et al. (2015) | *Computers in Human Behavior* | Log data | ML | Learner progress |
| Reese et al. (2015) | *British Journal of Educational Technology* | Log data | ML | Learner progress |
| Snow et al. (2015) | *Computers & Education* | Log data, pre-posttest | HE | Student performance, student behavior |

[a]Note: *ES* elementary school, *MS* middle school, *HS* high school, *HE* higher education, *TR* training, *ML* multilevels

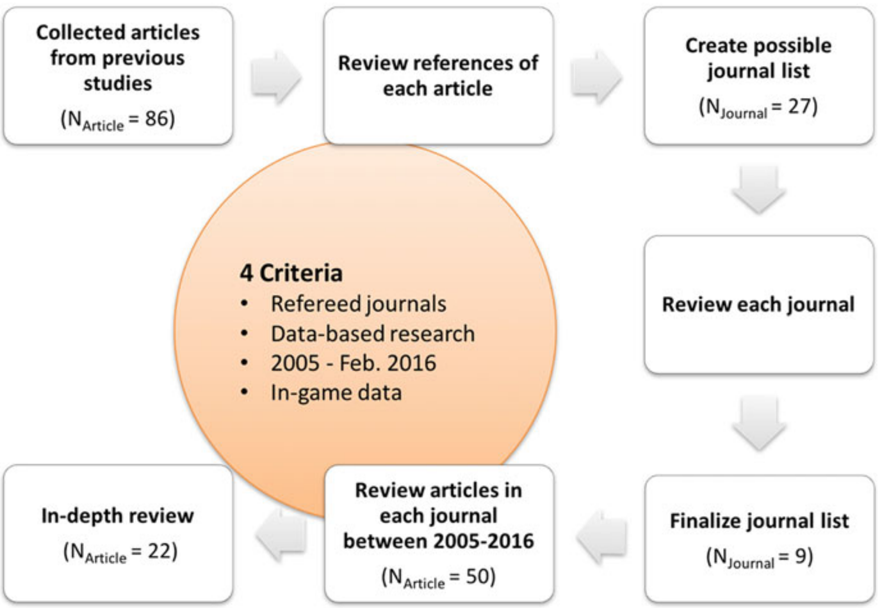


**Fig. 24.1** Our selection process

(Strauss and Corbin 1990) in sorting and analyzing the articles. For the first round, the references of the 22 articles were entered into a spreadsheet. Guided by our research questions, the following information, serving as the column headings, was extracted from each article:

- Authors
- Research topic
- Game name
- Data source
- Data analysis (statistical analysis)
- Visualization/software used
- Sample (n)
- Grade level
- Subject area
- Journal

For the data source element, we double-checked if the authors used "in-game logs." For the second round, we further categorized the articles using the following coding scheme based upon the content of the articles: level, subject matter, and relevant topics that also served as column headings for each article.

- Level—at which level the study was conducted at:
  - ES—elementary
  - MS—middle school
  - HS—high school
  - HE—higher ed
  - TR—training
  - ML—multilevels
- Subject matter—for what subject matter the study was conducted in:
  - Sci: science
  - L: language
  - T: thinking skills—critical thinking/problem solving
  - M: math
  - Cs: computer science/programming
  - Me: medical
- Relevant topics—for which research question(s) of our review this article is relevant to:
  - C: challenge (RQ4)
  - O: performance/learning outcomes (RQ2)

    O—outcomes
    A—attitudes
    E—emotions
    B—behavior

M—motivation
EP—experience
SC—students' characteristics

Each article classification was reviewed and verified by a second researcher. During this iterative analysis process, the researchers met frequently to discuss themes that emerged to identify and refine categories until a consensus of grouping was reached. The findings of this review are presented in the next section.

## 24.3 Findings and Discussion

In this section, we discussed the findings as showed in the review according to the five research questions we asked.

### *24.3.1 What Issues Have Researchers Been Investigating on Using Learning Analytics in SG (RQ1)?*

The first research question sought to identify which topics and issues were most commonly studied when researching utilized learning analytics. The results of the review indicated that the 22 studies have largely focused on the efficacy of SG and factors that relate to the use of SG such as game design, motivation, and student engagement. The findings revealed that learner performance ($n = 13$) and game design strategies ($n = 7$) were the two most common topics. Less common topics included motivation ($n = 6$), student behavior ($n = 5$), problem solving ($n = 4$), learner progress trajectories ($n = 3$), and student collaboration ($n = 2$). It should be noted that there were several studies that investigated multiple topics. For example, Gauthier et al. (2015) were interested in learning outcomes, game design strategies, motivation, and problem-solving strategies. A discussion of the included articles, their research topics, and issues is presented below (Table 24.2).

**Table 24.2** Topics[a]

| Category | Number of studies |
|---|---|
| Student performance | 13 |
| Game design strategies | 7 |
| Motivation | 6 |
| Student behavior | 5 |
| Problem-solving strategies | 4 |
| Learner progress trajectories | 3 |
| Student collaboration | 2 |

[a]An article often focused on more than one topic

#### 24.3.1.1 Student Performance

The most prevalent topic in this review was that of learner performance ($n = 13$). These studies analyzed learner performance in conjunction with other research topics. For instance, four studies investigated the effects of student behavior on learning performance. Snow et al. (2015) investigated the effect of student agency on learning outcomes. By logging student interactions with specific game features, the researchers were able to "... quantify variations in students' choice patterns and examine how these different trajectories impacted students' learning outcomes" (p. 384). Liu et al. (2016) studied learner behavior and performance through log data of cognitive tool use in a SG designed for middle school students. In their study, the log data included the frequency and total time spent using each of the 12 tools, and examination of the log data was connected to students' performance. Cheng et al. (2015) also investigated student's learning outcomes in a similar manner to the research by Liu and her colleagues by evaluating in-game learner behaviors such as frequency and duration of time that students spent viewing relevant material. In a study by Liao et al. (2011), gameplay data such as participants' learning time, attempt frequencies, and frequencies of correctness were used to support the qualitative data to evaluate the effectiveness of the game environment. Results showed that the game positively influenced players' cognition.

Gauthier et al. (2015) were interested in how student usage rate of a study aid affected problem-solving strategies and learning outcomes. They tracked the study-aid use sessions, the tasks attempted, and tasks completed. With a similar focus on solving strategies and learning outcomes, Kerr and Chung (2012) used cluster analysis to evaluate learner performance. Their goal was to identify key features of learner proficiency by logging deliberate actions via mouse clicks during gameplay. Based on this study, Kerr (2015) revised the video game and conducted another study to examine the effectiveness of the new version of the game. In another study, Cagiltay et al. (2015) examined students' learning outcomes at various levels of competition. They tracked their in-game performance of a drill and practice educational game. The game recorded the performance through measures of accuracy and response time. Unlike Cagiltay et al. (2015) who focused on competition, Burton and Martin (2010) primarily focused on student collaboration. They evaluated chat logs in hope of determining learning outcomes by identifying whether elements of collaboration and a knowledge spiral were present.

Loh and his colleagues conducted three studies in evaluating performance in order to distinguish between novices and experts (Loh and Sheng 2013, 2014; Loh et al. 2015). These studies used a string similarity index that measured the in-game code action sequences of learners and compared their performance to expert solutions. Finally, Spires et al. (2011) used computer trace data of in-game performance to measure learning outcomes. They evaluated performance by recording how many goals were met during gameplay.

#### 24.3.1.2 Game Design Strategies

The second most prevalent topic was game design strategies ($n = 7$). This topic included studies that implemented learning analytics to specifically investigate how a serious game might be improved. For example, Klopfer et al. (2012) used log data such as hours of play and frequency of gameplay in order to evaluate when and how students play SG on mobile devices so that the game could be made more "... appealing, educationally useful, and practical" (p. 472). Klopfer et al. (2012) first reported their game design choices toward building an engaging and educational game, and then they reported the findings of their pilot study. Their primary concern was to evaluate student engagement through gameplay habits outside of school hours when students often have more choices for activities. The log data showed students' engagement. The peak hours of gameplay occurred after school, and some students even snuck their phones into school to play the game at lunch. Next, Kerr (2015) employed cluster analysis and data mining to determine how to improve the game's design. Similar to Kerr and Chung (2012), the data were recorded from mouse clicks of deliberate actions in the game.

Unlike Klopfer et al. (2012) and Kerr (2015) who only evaluated a singular game design, Liao et al. (2011) evaluated multiple designs in order to assess whether or not they engaged the learners. To do so, they manipulated the nature of the relationship between the learner and a virtual pet. The three game design strategies included (1) nurturing the virtual pet to stimulate learning, (2) changing the pet's appearance in accordance with the student's learning status, and (3) the virtual pet acting as a facilitator of knowledge. In order to investigate which approach kept the learners engaged, Liao et al. (2011) implemented a survey in conjunction with monitoring time on task, attempted frequencies, and the number of questions correctly solved. The results revealed that all three strategies were effective in keeping the learners engaged. Similar to Liao et al., Gauthier et al. (2015) studied the effect of game design strategies on student engagement. As mentioned previously, the study compared two types of study aids. One was an online study-aid game that leveraged game elements such as the completion of mini goals and the use of power-ups, while the other online study aid did not utilize any game elements in its design. The results of the study revealed that the gamified study aid promoted more specific problem-solving strategies, greater student engagement, and higher success rates. Sun et al. (2011) studied problem-solving strategies through multiple game designs. They attempted to identify the most effective game designs by comparing three in-game scaffold types: critical feature marking with frustration control, critical feature marking with demonstration, and a control condition with no scaffolds. They tracked in-game data such as accuracy and unassisted placements to determine how the scaffolds were used as well as how they affected the problem-solving strategies. The results showed that both scaffold conditions significantly improved accuracy and decreased unassisted placements.

The last two studies investigated game designs in relation to group processes. First, Cagiltay et al. (2015) explored the effects of game design, specifically competition, on learning outcomes and motivation. Their study measured the number of questions answered correctly as well as the total reading time and total response time. In contrast to student competition, Hämäläinen (2008) studied game designs relating to student collaboration. The study leveraged in-game data such as overall time spent on the game to evaluate performance of individuals and the group as a whole.

#### 24.3.1.3 Motivation

Motivation ($n = 6$) was the third most frequent category. This included student engagement and interaction. Most of the digital games, SG in particular, rely heavily on the engagement of the players to be successful. In Kiili's (2005) study of how educational games afforded flow experience, 18 university students played an educational game named *IT-Emperor*, which was designed to facilitate flow experience—a state of complete absorption or engagement in an activity that tends to have a positive impact on learning (Csikszentmihalyi 1991). In order to determine the usefulness of content creation challenges included in the game and factors that influence flow experience, log data, a questionnaire, a posttest, and interview results were analyzed. In particular, in-game data was used to track players' achievements at every phase, the characteristics of their output, as well as their behavior patterns. The findings demonstrated that half of the participants experienced flow during gameplay, which was stimulated by content creation in the game. Besides providing highly engaging learning affordances, another notable feature revealed by this study was that SG also stimulated collaboration among learners. In another study, Forsyth et al. (2013) leveraged a discussion log between students and an intelligent tutor system (ITS) in a SG to predict the student's motivation. They included measures of student discourse elements such as verbosity and quality of answers as well as ITS discourse elements such as hints, prompts, feedback, and questions. The results revealed that both verbosity and the quality of answers were positively correlated with student engagement. It is worth noting the studies focusing on motivation and engagement often included the study of game design strategies as shown in multiple studies ($n = 4$) which used measures of motivation to either inform or evaluate the game design strategy (Cagiltay et al. 2015; Gauthier et al. 2015; Klopfer et al. 2012; Liao et al. 2011).

#### 24.3.1.4 Student Behavior

The studies about student behavior ($n = 5$) focused on in-game behavioral patterns and learner choices. Hou (2012) sought to understand learner behavior frequencies within an educational MMORPG (massively multiplayer online role playing game).

This study analyzed learner behavior patterns by recording all movements (e.g., keystrokes) and events (e.g., completing a task). All data were then categorized into ten behavioral categories such as using a tool, trading items, or managing pets. Liu et al. (2016) also used learning analytics in a serious game to study learners' use of integrated tools such as a notebook and multiple databases. Both the frequency and duration of each tool's use were logged to evaluate learner behavior. Similar to Liu et al. (2016), Cheng et al. (2015) logged information about the frequency and total duration of time that learners spent viewing relevant materials during gameplay. Their study also recorded which characters were used, the amount of characters chosen, and the number of rounds played. These variables were then measured and correlated with learning outcomes. Their study found that in-game performance had a positive correlation with the frequency and overall time spent viewing the relevant materials. As mentioned previously, Snow et al. (2015) investigated student agency and its effect on learning outcomes. They varied the amount of choices available to the student and logged student interactions with specific game features. The researchers used three quantitative methods (random walks, Euclidean distances, and entropy scores) to measure and visualize the learners' choice patterns.

#### 24.3.1.5 Problem-Solving Strategies

Four studies used learning analytics to investigate problem-solving strategies. The studies in this category focused largely on the specific strategies that learners implemented to solve problems. For example, Gauthier et al. (2015) studied problem-solving strategies by evaluating study-aid use by the learners who were given either a study-aid game or a nongame study aid. The study leveraged telemetric data such as, "play sessions, tasks attempted, tasks completed, average moves per task, and interactions with various game elements" (Gauthier et al. 2015, p. 28) to indicate problem-solving strategies. Likewise, Sun et al. (2011) sought to identify specific solving strategies. Their study measured gameplay markers such as unassisted placements, number of restarts, and incorrect solutions in a puzzle game to identify solving strategies such as elimination techniques or trial and error. Using this data, the study evaluated whether scaffolding types affected problem-solving strategies by providing guidance or by increasing reliance on the scaffolds. Additionally, Kerr and Chung (2012) studied solution strategies by tracking learner actions through mouse clicks. The study was able to differentiate between students who used a systematic guess-and-check strategy and students who simply guessed randomly. Finally, Liu et al. (2011) used in-game activity logs to indicate how learners solved problems. Their study examined how frequently learners performed five problem-solving strategies: "solution development, experimenting, solution review, solution reuse, and reading the tutorial" (Liu et al. 2011, p. 1912) in conjunction with a survey that inquired about perceived affective states such as anxiety, boredom, and flow. The authors found that specific problem-solving strategies were more likely to occur depending on the learner's affective state.

#### 24.3.1.6 Learner Progress Trajectories

Three studies that investigated learner progress and trajectories focused on measuring completion time and achievement rates. The study by Reese et al. (2015) investigated the modeling of learning trajectories toward multidimensional goals, achievement rates, acceleration and deceleration of the achievement rate, and standardized metrics of achievement. A timed report instrument was used to continuously measure gameplay elements every 10 s. Minović et al. (2015) also investigated whether an instrument could evaluate learning progress with the goal of providing real-time data visualization that would inform both teachers and learners of gameplay progress. In their study, performance was evaluated using the learner's progress through required steps within quests. In evaluating learner progress trajectories within a SG, Hämäläinen's study (2008) used measures such as the overall completion time of the game and the completion time of each phase of the game to view the learner progress throughout the game. However, this study diverges from the other two previously mentioned in this section in that Hämäläinen also examined each learner's progress within a collaborative group. As this study also focused heavily on student collaboration, it will be discussed in greater detail below.

#### 24.3.1.7 Student Collaboration

Only two studies examined student collaboration. Research on this topic tended to focus on how to promote collaboration using SG. As mentioned previously, Hämäläinen (2008) investigated completion times and learner progress. However, the study primarily focused on the effects of scripting group interactions and activities toward promoting student collaboration. The study used epistemic collaboration scripts, which provided additional structure in the form of directions and shared learning tasks in order to guide students in their individual knowledge construction and their group collaboration as they learned how to deal with in-game tasks. In-game chat logs as well as audio recordings were used to evaluate the level of collaboration within each group. The results of the study indicated that scripting promoted student collaboration and supported learner progress. The second study by Burton and Martin (2010) explored how student collaboration might impact the knowledge creation process in a virtual environment. In order to indicate when collaboration occurred, the study analyzed the discussion of participants throughout the game via a chat log. Finding of this study is detailed in the next section.

### *24.3.2 What Research Evidences Are There in Using Analytics to Support Teaching and Learning Through SG (RQ2)?*

Learning analytics are frequently used in SG to measure the effectiveness of the games by closely analyzing learners' behavior patterns. The previous section provided an overview of the topics and issues the studies examined. In this section, we discuss more in-depth findings of nine studies that employed the use of learning analytics to investigate how SG impact learning in different subject areas. Specifically, these studies addressed how game elements influenced learning outcomes by examining players' in-game behaviors and learning strategies (Burton and Martin 2010; Cagiltay et al. 2015; Cheng et al. 2015; Gauthier et al. 2015; Kerr 2015; Kerr and Chung 2012; Liao et al. 2011; Snow et al. 2015; Spires et al. 2011). In general, these articles suggested that learning analytics were useful in understanding students' learning trajectories and reported that SG can have a positive impact on learning.

Burton and Martin (2010)'s mixed-design case study found that SG is conducive to learning in terms of fostering meaningful interactions. In this research, 28 college students enrolled in computer programming courses were invited to collaborate in a 3D VLE (virtual learning environments), which was designed to improve their programming skills and give them experience in programming and working with a 3D game engine. Data from this study were gathered through three sources: conversation log files from the 3D virtual environment, a survey, and follow-up interviews. From the analysis of the in-game conversations, five forms of collaboration (elementary clarification, in-depth clarification, inference, judgment, and application) emerged and were shown to amplify the knowledge creation process. Besides, four modes of knowledge creation (socialization, externalization, combination, and internalization) were observed as well. With supporting evidence from the survey and interview results, this case study suggested that by allowing students to interact effectively with each other using a myriad of collaborative elements, the opportunity for all modes of knowledge creation could be enhanced.

In Liao et al.'s (2011) pilot study, nine 10-year-old fourth grade students from Taiwan played a handheld pet-nurturing game named *My-Mini-Pet* designed to help students understand arithmetic practices. Gameplay data such as participants' learning time, attempted frequencies (the number of math questions they tried to solve), and frequencies of correctness (the number of the questions they solved correctly) were used to support qualitative data to evaluate the effectiveness of the game environment. Results showed that the game positively influenced players' cognition and affectivity by sustaining their interests and facilitating discussions and lengthened their learning time.

Spires et al. (2011) studied eighth grade students' learning gains after playing *Crystal Island*, a game that required students to solve a science mystery based on microbiology content. One hundred and thirty-seven participants' in-game performance traces, namely, the number of goals they had completed, were collected and analyzed. Results indicated that the effective exploration and navigation of the hypothesis space in a problem-solving task were predictive of student learning. Specifically, students who selected a higher proportion of appropriate hypotheses demonstrated greater learning gains on the posttest and completed more in-game goals. The researchers concluded that hypothesis-testing strategies played a crucial role in narrative-centered learning environments, thus demonstrating their connections to learning gains and problem solving.

Kerr and Chung (2012)'s research aimed to examine the utility of cluster analysis to identify students' performance in educational video games. Fuzzy feature cluster analysis was adopted as a method to extract the key features of student performance from the restructured log data stemming from the game. Their findings suggested that cluster analysis can identify three mathematical misconceptions ("partitioning errors," "unitizing errors," and "adding errors") that were indications of players' lack of understanding of specific knowledge specifications and two game misconceptions ("everything in order" and "misusing resources") that were unrelated to the mathematical concepts being addressed in the game. Cluster analysis also identified similar key features of student performance in similar situations. Of the 18 game levels analyzed, cluster analysis identified key features of student performance in all but two levels, or 89% of the time. These results supported the notion that cluster analysis can consistently identify key features of student performance in the form of solution strategies and error patterns across levels, which contained few extraneous actions and explained a sufficient amount of the data. In light of these findings, Kerr (2015) revised the video game used in his study and conducted another study to examine the effectiveness of the new version of the game. Results showed that while playing the upgraded version of the game, students used incorrect mathematical strategies significantly less often than they did in the original version of the game. Moreover, students' perception of the game became more positive even though no significant difference was found in terms of learning outcomes. These findings suggested that data mining results could be used to make targeted modifications to a game that increased the interpretability of the data without negatively impacting student perception or performance.

Another example employing data mining techniques to discern students' learning strategies in SG is the study conducted by Snow et al. (2015), which explored the impact of students' controlled behaviors within a game system called *iSTART-2* (Interactive Strategy Training for Active Reading and Thinking). This research is comprised of two studies designed to investigate how agency manifested within students' choice patterns and ultimately influenced self-explanation quality. A total of 145 college students participated in this research. Random walk and entropy analyses were used to process in-game data, quantify the amount of control demonstrated in students' choice patterns, and determine the relationship between variations in these patterns and students' learning outcomes. Results indicated that students who demonstrated more controlled choice patterns generated higher quality learning outcomes compared to students who exhibited more disordered choice patterns.

Cagiltay et al.'s (2015) research explored the educational impact of an online study-aid game for studying human vascular anatomy versus a similar nongame study aid and how it related to medical students' demographic traits and voluntary use over a 35-day period. 46 first-year medical anatomy students in a Canadian university were involved in this study. Learners' tool-use data were extracted from the game system recording students' in-game behaviors such as tasks completed, tasks attempted, unique vessels visited, moves per task, and achievements earned.

These logs were used to compare with two-tailed non-parametric Wilcoxon tests in order to determine whether or not participants exposed to the game learned more and used their study aid to a greater extent than the control group. Hierarchical linear regression models revealed that study-aid success rate (a metric for assessing performance through the study aids) was a significant predictor of anatomy test improvement with the game, but not for the nongame. The researchers' analyses implied that game mechanics encouraged more specific problem-solving strategies than the control study aid did, leading to greater predictability of learning outcomes.

Gauthier et al. (2015) compared a game, *Vascular Invaders*, and a nongame study aid, *the Vascular Anatomy Study Aid*, both designed for medical anatomy students aiming at exploring how game design affects learning and voluntary study-aid use in an unstructured, informal context. Students' click-stream data were collected from both the experimental and control groups. Specifically, statistics such as use sessions, attempted tasks, and completed tasks were used to analyze students' interactions with specific game elements and engagement. The result of this study implied that game features, such as rules, penalties, leader board, achievements, points system, and story line, could motivate increased voluntary use of the game by medical students. Moreover, this study also revealed that study-aid performance was a significant predictor of learning outcomes in the game group but not in the control group, which confirmed the hypothesis that higher performance in the game was indicative of greater learning.

Cheng et al. (2015) observed in-game data about the frequency and total duration of time that learners spent viewing relevant materials during gameplay, in order to understand the interplay of student concept learning, gaming performance, and in-game behaviors. A total of 62 seventh graders took part in their study and played *Virtual Age*, an SG developed to enhance students' understanding of biological evolution. A MySQL database was also created to record how students interact with in-game characters, including the in-game characters being used, the number of times of the in-game characters being reproduced, the duration and the number of times of viewing the status information, the duration of viewing the symbiosis and decomposer information, the total rounds being played, the total amount of characters being used, and student gaming performance (game score). These log files were used to examine their correlation with gaming performance, which subsequently influenced learning outcomes. Findings supported that the sound and sophisticated game design of *Virtual Age* was effective for learning about biological evolution given the situated interactions between learners and the game mechanism.

### 24.3.3 What Techniques Have Been Used to Investigate Analytics in SG (RQ3)?

For the 22 studies reviewed, two primary techniques were revealed in studying the analytics in SG: game features and/or metrics and data visualizations.

#### 24.3.3.1 Game Features and Metrics

There was a tendency to develop appropriate features or metrics to find evidences of learning performance in SG analytics. The features extracted from gameplay data can be used as an evidence to indicate different levels of proficiency, expert-novice behaviors, or learning progress (Kerr and Chung 2012; Loh and Sheng 2013, 2014; Loh et al. 2015; Reese et al. 2015). Kerr and Chung (2012) examined the utility of cluster analysis to identify key features of student performance in log data generated by a game called *Save Patch* designed to address mathematical concepts in sixth grade. One hundred and fifty-five participants played the game for approximately 40 min, and the game recorded each student's actions as they interacted with the game throughout a total of 18 levels. This study found that the cluster analysis was able to identify different kinds of strategies and error patterns and a specific strategy can be interpreted as mathematical misconceptions. However, some strategies were not clear indications of student mathematical understanding.

Researchers have attempted to quantify learning trajectories as learner progress toward the game goal. Reese et al. (2015) validated learning dynamics as standardized metrics to assess learner progress in the game *Selene*, including (1) learner progress toward the learning goal, (2) the rate of progress, and (3) changes in that rate. The game quantified learning trajectories as the learner progresses toward the learning goal by implementing a timed report instrument which recorded gameplay data every 10 s (Reese et al. 2012). This study used 267 participants' aggregated timed report data. The participants completed three rounds of assessments (pre, medial, and post) and two rounds of gameplay. The researchers analyzed the timed report data using mixed model analyses. This study built upon their previous study that found that some students showed linear trajectories, while others showed curvilinear trajectories (Reese et al. 2012). In this study, the researchers developed an approach to deal with model differences in learning trajectories of learner achievement for multidimensional learning goals. The findings confirmed that the timed report data successfully quantified learning trajectories when a game embedded multidimensional learning goals. In addition, timed report data indicated rate of learner progress and changes in the rate and supported standardized metrics of learner progress and game effectiveness.

Indicators of expert-novice behaviors in SG have been developed using various measures such as time-to-task-completion rate, mental representations, and neural responses (e.g., Cappiello et al. 2011; Kozma and Russel 1997; Mishra et al. 2011). More recently, researchers have used action sequences (a learner's chronological order of actions; task-based) to investigate expert-novice behavioral differences as a predictor for learner performance measurement in games (Loh and Sheng 2013, 2014; Loh et al. 2015). Loh and Sheng (2013) examined a list of common string similarity metrics that can differentiate likely experts from a group of unlabeled students. String similarity metrics is a method based on how similar students' action sequences are to action sequences of experts. Their study showed that string similarity metrics as a performance metric in SG was able to distinguish likely experts from novices. In a follow-up study, Loh and Sheng (2014) investigated the effectiveness of various metrics by comparing Jaccard coefficient with other game metrics such as time of completion, distance traversed, and number of conversations. The Jaccard coefficient is a measure of similarity between two strings of expert and unlabeled student. For example, a Jaccard coefficient of 1 indicates the two strings are identical; that is, the student is a likely expert, while a Jaccard coefficient of 0 indicates the two strings are totally different; that is, the student is a novice. The finding of this study showed a Jaccard coefficient was the most significant predictor of performance assessment. Most recently, Loh et al. (2015) developed an alternative method to code action sequences called tile-based or navigational action sequences. They first divided the game navigation map into grids of different sizes (e.g., $5 \times 5$, $10 \times 10$, $15 \times 15$). Based on the order of the map grid (i.e., each student's pathway in a game), they calculated a student's navigational action sequence in the form of Jaccard coefficient. They showed both task-based and tile-based action sequences were powerful predictors for SG analytics.

#### 24.3.3.2 Data Visualization

Data visualization has emerged in recent years as a new tool for tracing students' learning progress and presenting students' knowledge understanding. Three studies showed that various visualization techniques can offer new opportunities of examination of dynamic gameplay data captured in SG (Liu et al. 2016; Minović et al. 2015; Snow et al. 2015). Liu et al. (2016) incorporated visualization techniques to examine students' behavior patterns with different characteristics in a SG (see Fig. 24.2). The researchers employed a multiple-case approach. The participants were sixth graders from one middle school in each case (38 students in Case #1, 64 students in Case #2) who played the game, *Alien Rescue*, as their science curriculum unit for approximately 3 weeks. In Case #1, they examined the students' tool use as captured in the log data with different levels of learning performances using the students' game solution scores and science knowledge test scores. In Case #2, they investigated the students' tool use with different levels of fantasy-related factors: fantasy proneness, game engagement, and alien information acquisition. The students were grouped into high and low levels of each variable to examine whether students with different characteristics exhibited different tool-use patterns. The statistical analyses in combination with data visualizations showed that behavior patterns varied according to students' different learning characteristics (i.e., learning performance, fantasy proneness, and game engagement). For example, high-performing students used tools more appropriate for their problem-solving processes. The findings revealed the patterns that previously were not possible to detect without data visualizations and also provided support to the previous literature that showed different learning behaviors by students with different characteristics.

Snow et al. (2015) investigated students' interactions within the game, *iSTART-2*, and the relationship between students' behavior patterns as shown in the log data and their learning outcomes (i.e., self-explanation quality). The 75 college students

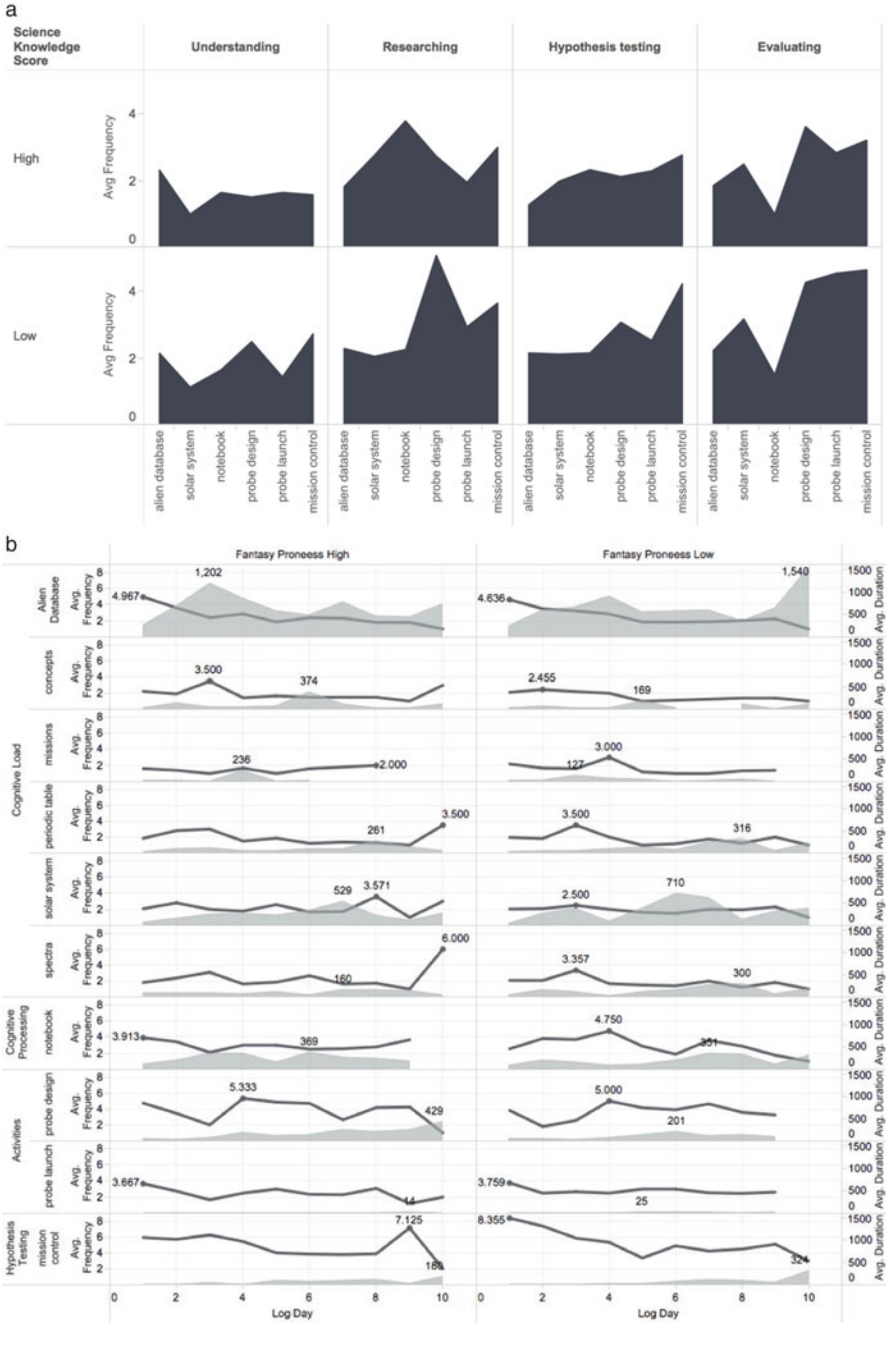


**Fig. 24.2** Examples of visualization of student tool use by different student characteristics (Liu et al. 2015, pp. 45–47). (**a**) Student tool use by high and low science knowledge groups (Case #1). (**b**) Student tool use by fantasy proneness groups (Case #2)

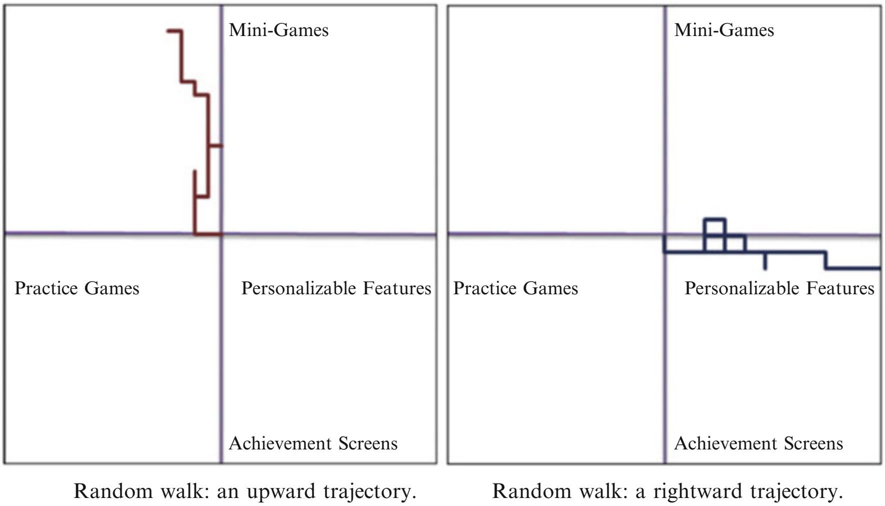


**Fig. 24.3** Examples of random walk (Snow et al. 2015, pp. 385–386)

participated a 3-h session consisting of a pretest, training and practice via the game, and a posttest. The researchers used three dynamical techniques including random walks, Euclidean distances, and entropy scores to visualize students' choice patterns. Random walks captured each student's sequential order of interaction with the features (represented by four game-based feature categories) within the game and visualized their interaction trajectory within the system in an X, Y scatter plot graph (see Fig. 24.3). Then, Euclidian distance quantified each student's movements as shown in their interaction trajectory. Finally, entropy quantified the degree to which the student's movements were controlled or disordered. For example, if a student's entropy score is low, it indicates a highly organized pattern. Conversely, a high entropy score indicates a disorganized pattern. The findings showed the relationship between entropy scores and students' performance. Specifically, students who showed low entropy scores generated high-quality self-explanations and performed better within the game. These results confirmed their previous study showing the positive influence of students' controlled behaviors on learning outcomes.

Minović et al. (2015) proposed a new tool that tracks student learning progress and visualizes student learning model in real time. In this study, a form of circular graph was developed to visualize a learning model not only for an individual student but also for the whole group (see Fig. 24.4). The circular graph provides both the overall percentage of entire knowledge domain model and the learning progress on each domain concept. The information provided throughout the visualization can enable teachers to improve students learning outcomes or control a level of challenge embedded in the game based on each student's learning performance. To evaluate this proposed visualization, the researchers conducted an empirical

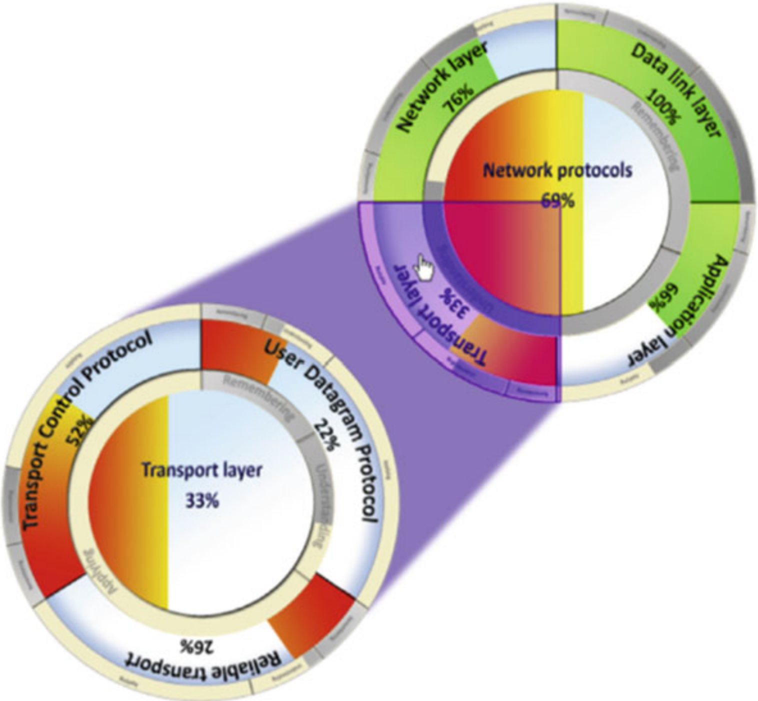


**Fig. 24.4** Example of visualization of student knowledge (Minović et al. 2015, p. 104)

study, in which 20 students played an educational role-playing game for 15 min and six educators monitored the students' gameplay. The game recorded the students' interactions with nonplaying characters and their quiz choices. A set of tools enabled the educators to track the students' progress during the game session. The finding showed this new visualization tool can track students' learning progress, detect, and solve problems relevant to learning. The study suggests, given the tracking information generated by the tools, educators can help students' game activities to improve their learning outcomes.

### *24.3.4 What Challenges Have Researchers Identified in Using Analytics for SG (RQ4)?*

Researchers have reported various challenges of studying SG analytics. These challenges include data preprocessing, data analysis, and data interpretation. In the context of this review, game system typically records large quantities of user interaction data in the form of log files. A challenge is data preprocessing to ensure the quality of data and extract meaningful attributes for further analysis. Liu et al. (2015) discussed the challenge of data cleaning for a research project conducted in a real-world setting. The participants of the study used the game in a real classroom setting, in which some students did not complete all measures for various reasons (e.g., student absence) during the entire period of game use. The researchers also reported the challenge of identifying and taking out meaningless actions or interactions caused by such as computer crashes or switching computers among students. Reese et al. (2015) also noted that the analyses were limited to data for only valid participants who completed the entire game *Selene*; for example, the number of the valid participants was 411, while the registered players were 767. Excluding incomplete or meaningless records often resulted in reducing the sample size.

Kerr and Chung (2012) discussed the challenge of identifying the relationship between how students built knowledge or faced misconceptions using large quantities of data to identify meaningful features of student performance (e.g., using observable variables such as student actions in mouse clicks, keystrokes) and student performance was not immediately clear. Few theories exist to guide whether certain actions are relevant to student understanding. Extracting key features of student performance from gameplay data is one of the essential steps to understand student behaviors such as strategies or mistakes. To address these challenges, the researchers described the processes of data preprocessing in detail. The raw gameplay data were transformed to a compact structure for further cluster analysis. First, the user-generated data in the composite library were stored for the purpose of recording user actions reflecting understanding of knowledge specifications. Then, a code was assigned to each of the user actions for the purpose of categorizing similar actions. In order to deal with the issue that the same action might have different meanings at different levels, a series of datasets in each level was separately created.

Another challenge is to determine an appropriate technique to analyze the pre-processed data. Kerr and Chung (2012) compared fuzzy and hard cluster analyses. They confirmed that fuzzy clustering supports analyzing gameplay data and hard clustering supports analyzing test item data. Hard clustering can be used to discover multidimensionality and conceptual similarity among test items. Compared to test item data, gameplay data are not linearly separable, with which fuzzy clustering can be used to address the issues such as “nonseparable clusters” or “unequal cluster populations” (Kerr and Chung 2012, p. 168). Specifically, when the data is very fuzzy, which can be found by calculating Dunn coefficients (ranging from 0, indicating very fuzzy data, to 1, indicating completely partitioned data), fuzzy cluster analysis would be more appropriate than hard cluster analysis. The findings of these studies confirmed the need for providing evidences to determine appropriate methods to identify key features of student behaviors as captured in gameplay data.

#### 24.3.4.1 Are There Any Trends Shown in the Review (RQ5)?

Given the findings of this literature review, we have observed the following trends. There has been an increase in the number of SG analytics studies published between 2005 and 2015 (see Fig. 24.5), suggesting a growing interest in the use of SG analytics. In this review, only one empirical study was published in 2005, while there were nine studies in 2015. Table 24.3 shows the journals that the 22 articles were published in.

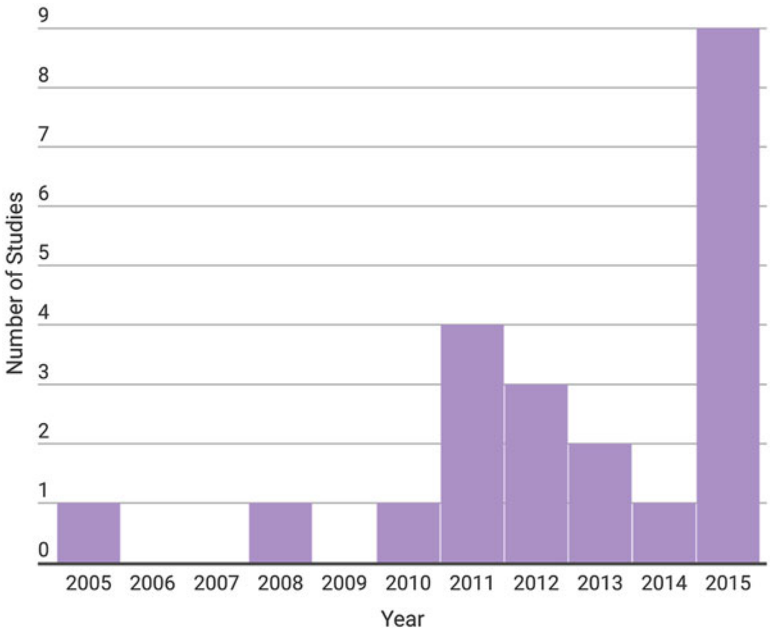


**Fig. 24.5** Articles published by year

**Table 24.3** Journal list in which the reviewed articles were published

| Journal name | Number of studies |
|---|---|
| *British Journal of Educational Technology* | 1 |
| *Computers & Education* | 8 |
| *Computers in Human Behavior* | 3 |
| *Education and Information Technologies* | 1 |
| *Journal of Computer Assisted Learning* | 2 |
| *Journal of Educational Computing Research* | 2 |
| *Journal of Educational Data Mining* | 3 |
| *Technology, Knowledge and Learning* | 1 |
| *The Internet and Higher Education* | 1 |

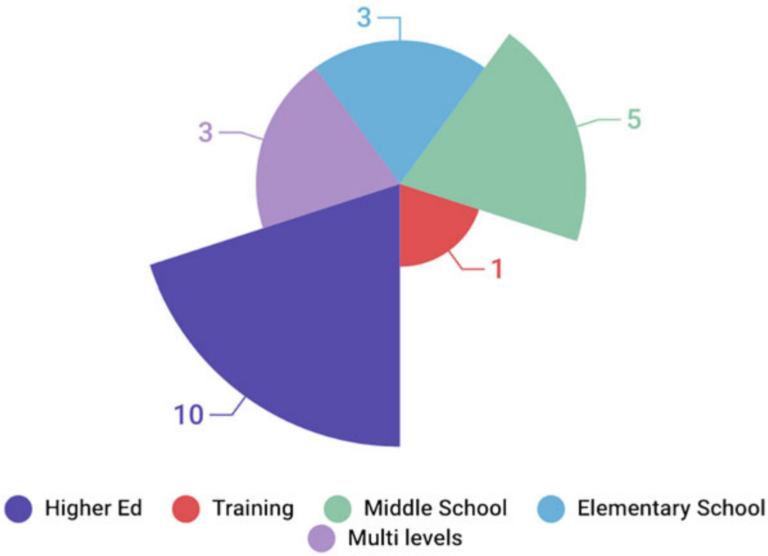


**Fig. 24.6** Education levels

**Table 24.4** Subject matter distribution

| Subject matter | Number of studies | Percentage of total (%) |
|---|---|---|
| Science | 6 | 27.27 |
| Thinking skills | 6 | 27.27 |
| Computer science | 4 | 18.18 |
| Mathematics | 3 | 13.64 |
| Language | 1 | 4.55 |
| Medical | 1 | 4.55 |
| Usability | 1 | 4.55 |

In identifying the education levels most frequently used for the participants, the findings showed that the majority of learning analytics research was conducted with participants from higher education ($n = 10$, 45.45%; see Fig. 24.6). Other studies included participants from middle school ($n = 5$, 22.73%), elementary school ($n = 3$, 13.64%), and industry training ($n = 1$, 4.55%) and, interestingly, none at the high school level. The prevalence of higher education students may be due to convenience as higher education students are often much more readily accessible to researchers for such studies.

Table 24.4 shows the distributions of the studies by the subject areas in which the research was conducted. The results revealed that science ($n = 6$), thinking skills ($n = 6$), computer science ($n = 4$), and mathematics ($n = 3$) were the most dominant subject matters that the SG used in the 22 studies. Less common subject matters included language ($n = 1$), medical ($n = 1$), and usability ($n = 1$). This finding showed the disciplines in which learning analytics is of particular interest to researchers.

The findings of this review also showed several studies investigated multiple topics. Two most common topics were learner performance ($n = 13$) and game design strategies ($n = 7$), followed by the other topics including motivation and student engagement ($n = 6$), student behavior ($n = 5$), problem solving ($n = 4$), learner progress ($n = 3$), and student collaboration ($n = 2$) (see Table 24.2). When accounting for the research topics, learner performance was the predominant research topic. This finding is consistent with a recent study by Loh and Sheng (2014), in which they noted that SG research has focused more on users' behavior captured within the game environment in situ as evidences of users' learning performance.

In general, the results from the majority of the studies investigating students' learning performances by examining students' learning trajectories through log data indicated that SG had a positive impact on learning ($n = 6$; Burton and Martin 2010; Cagiltay et al. 2015; Cheng et al. 2015; Gauthier et al. 2015; Kerr 2015; Liao et al. 2011; Spires et al. 2011), though one study did not find significant differences with or without the presence of game mechanisms in terms of learning outcomes (Kerr 2015). In most cases, well-designed SG influenced students' learning in both cognitive and affective aspects. Cognitively, sound game design encouraged higher frequency of learning tools used (Gauthier et al. 2015), facilitated discussions and collaborations (Burton and Martin 2010; Liao et al. 2011), helped learners formulate more accurate strategies (Cagiltay et al. 2015; Spires et al. 2011), reduced incorrect mathematical strategies (Kerr 2015), and ultimately enhanced their understanding of the learning content embedded in the games (Burton and Martin 2010; Cagiltay et al. 2015; Cheng et al. 2015; Gauthier et al. 2015; Kerr 2015; Liao et al. 2011; Spires et al. 2011). Affectively, effective game design elevated and sustained learners' interests and accounted for more positive perceptions toward learning (Kerr 2015; Liao et al. 2011).

The findings also showed that nine studies used only the gameplay data, while the other 13 studies used multiple data sources. Researchers showed the potential of using both dynamic (i.e., log data) and traditional (i.e., self-reports) measures of learning behaviors in order to provide in-depth understanding of student behavior patterns, their performance, and emotions behind those behaviors.

## 24.4 Implications and Conclusion

### *24.4.1 Implications for Future Research*

Based upon the findings of this review, we have identified several aspects for researchers to consider.

While there are more published studies in recent years, many more data-based research studies are needed, particularly at high school and industry training levels. This review showed learner performance and game design strategies were the two most common topics. Certainly, there is a continuing need for research on these two important topics. There is also a need for other less common topics such as motivation and engagement, student behavior, problem solving, learner progress trajectories, and student collaboration. Since these topics are often related to each other in examining students' performance, more research is needed to investigate the relationships among these variables.

The research reviewed showed the promise of using multiple data sources, both dynamic data (in-game data) and traditional measures, as well as combining emerging techniques such as visualization and traditional analyses such as statistical and qualitative analyses. More studies are needed for this emerging trend. Although various techniques are used, more data-based research is needed to understand the types of techniques and methods appropriate in different contexts of educational games.

The studies reviewed also indicated the challenge of cleaning and preprocessing the log data. A few studies have begun to identify and create a procedure for getting usable data. In order for more researchers to be able to use in-game data, some procedures and standards need to be established so possible matrix or frameworks used in one research could be useful for researchers in other studies.

### *24.4.2 Limitations of the Study*

Although we have gone through a long and careful selection process, it is possible even with our best intentions, we may have overlooked some peer-reviewed data-based articles. Given our criteria to review only refereed journal articles, we have intentionally excluded some book chapters that met our criteria. Our rationale for exclusion is it will be impossible to have a close-to-exhaustive list if book chapters are included as we do not have access to all books on the topic.

## 24.5 Conclusion

This review intended to provide a systematic review of data-based studies using analytics, especially in-game data such as logs, in SG. A total of 22 peer-reviewed studies using in-game log data are included in this review after a careful and deliberative selection process. These findings of the review showed learner performance and game design strategies were the two most common topics. Other topics included motivation and engagement, student behavior, problem solving, learner progress trajectories, and student collaboration. In addressing students' learning performances, more studies reported that SG had a positive impact on learning; and many highlighted the importance of game design. Some of the studies reviewed also indicated the challenges for researchers to use in-game dynamic data as a measure in research. Several trends are identified and implications for future research are discussed. We hope the findings of this review will lay a good foundation for researchers interested in using analytics in SG in their research.

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# Part IX
# Narrative Design

# Chapter 25
# Creating Story-Based Serious Games Using a Controlled Natural Language Domain Specific Modeling Language

**Olga De Troyer, Frederik Van Broeckhoven, and Joachim Vlieghe**

**Abstract** Creating serious games calls for a multidisciplinary design team, including game developers, subject-matter experts, pedagogical experts, and narrative designers. However, such multidisciplinary teams often experience communication and collaboration problems due to differences in terminology, background and the concerns of the people involved. As one step towards solving this problem, we developed a modeling language for authors of serious games to specify both the story and the pedagogical aspects of a narrative-based (i.e., story-based) serious game. The models created with the help of this language can then be processed in order to automatically generate (parts of) the game. The language is specifically designed to support the involvement of experts with a non-technical background. To achieve this, we employ a domain specific modeling language, i.e., a language specific for the domain of serious games and customizable to the terminology of the domain the serious game is dealing with. Furthermore, the language makes use of a Controlled Natural Language syntax and graphical notations. The combination of a domain specific vocabulary, a natural language syntax, and an easy to understand graphical notation allows different experts to be actively involved in the specification of the serious game, as such increasing consensus and enhancing quality. Furthermore, the model-based approach allows for a shortening of the development time of serious games (and therefore also their cost). As such, the approach tackles one of the major barriers for the development and widespread use of serious games. In this chapter, we present a complete overview of the domain specific modeling language and the associated tools developed to support the model-based approach.

**Keywords** Serious games • Narrative • Story • Pedagogy • Domain specific modeling language • Modeling • Controlled natural language • Graphical notation • Tools • Simulator

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## 25.1 Introduction

Serious games are widely recognized for aiding the acquisition of knowledge and skills, or to induce behavior changes. Compared to learning or training in a classroom environment, serious games support knowledge, skills or performance development in a controlled and responsive environment without the barriers of time and space, while using game mechanics to make learning more fun.

However, the popularity of serious games has raised the need for dedicated development methodologies and tools that can help to reduce the development time and costs (Bellotti et al. 2010). In addition, serious games should be based on sound learning theories and instructional design principles to ensure efficient and successful training and learning. This calls for a multidisciplinary design approach and a team of experts that includes game developers, subject-matter experts, pedagogical experts, and narrative designers (Rooney et al. 2009). Unfortunately, such multidisciplinary teams often experience communication and collaboration problems due to the different terminologies, backgrounds and concerns of the people involved (De Troyer and Janssens 2014) as well as the lack of suitable design tools that allow the experts with a non-technical background to be actively involved in the design process. As stated by Djaouti et al. (2010) "people without professional game design skills, such as teachers, corporate trainers, therapists and advertising professionals, request tools that could allow them to create or modify such games".

ATTAC-L is a tool that assists multidisciplinary teams in the creation of story-based serious games. This tool and its underlying methodology are specifically designed to enable experts with a non-technical background to participate actively in the design and modeling process of story-based serious games. To achieve this, we employ a domain specific modeling language (DSML). In this case, a language that is specific for the domain of serious games and that is customizable to the terminology of the topic (i.e., domain) of the game. Furthermore, the DMSL is using a Controlled Natural Language syntax in combination with a graphical representation. The use of a Controlled Natural Language (CNL) provides an easy human-readable, yet extensible and expressive way to formulate stories and specify story elements. The combination of a domain-specific vocabulary, a controlled natural language, and easy to understand graphical notation allows different experts to be actively involved in the specification of the stories and related pedagogical issues. As such, the DSML supports collaboration during the design process and has the potential to increase consensus among the experts. In addition, it provides a means for improved monitoring of the serious game's quality by the different experts.

A story-based serious game should include a compelling narrative, but should also be based on empirically validated pedagogical methods. To accomodate for this, the modeling language provides the means to specify the story as well as the links between the story models and the instructional design used in the serious game. In order to allow this, we introduced an annotation mechanism. Pedagogical aspects are specified as formal annotations on top of the story model. On the one hand, this allows and even gently urges designers to integrate proper pedagogical principles into the stories. On the other hand, this also helps to prevent that the specification of the learning and gaming aspects become too entangled inside the models. In other words, this way of working allows for the integration of pedagogical aspects into the story model while maintaining a clear distinction between the aspects and the narrative elements within the model. As such, different experts can concentrate on issues related to their own concerns (e.g., on the story, on how pedagogical objectives should be realized, etc.) without losing an integrated view.

The tool for designing story models with ATTAC-L is combined with others to form a model-driven authoring framework that facilitates the production of serious games at lower cost and with the active involvement of (non-IT schooled) domain experts (Van Hoecke et al. 2016). A model-driven authoring approach implies that the authors of the serious game create models, i.e., high-level conceptual specifications, which are then taken as input by tools to generate the actual game. To allow for early validation and testing of the story models, the authoring framework also provides a simulator. This is a kind of interpreter that executes the models directly, i.e., without code generation. The execution is performed, however, in a simple and predefined 3D environment with predefined Non-Player-Characters (NPCs) and predefined behaviors adapted to the topic of the serious game. In this way, the simulator can also be used as a fast prototyping tool. As such, the approach offered by the authoring framework has the potential of lowering some of the barriers that hinder the production of serious games, i.e., increasing the active involvement of experts without a technical background in IT and reducing costs.

The methodology and supporting tools for the authoring framework were developed within the Friendly ATTAC project (Friendly ATTAC 2012). This project aimed to develop a serious game for youngsters to help them deal with various cyber bullying issues. Cyber bullying, i.e., bullying via electronic communication tools, is a relatively recent phenomenon that occurs especially among early adolescents (12 to 15 year olds). Of course, the framework can also be used to develop serious games for numerous other purposes. Nonetheless, we will use fragments from the serious game developed in the context of the Friendly ATTAC project to illustrate the functionality and benefits of the DSML, i.e., ATTAC-L and the Simulator. By using the ATTAC-L tool the subject-matter experts in the Friendly ATTAC project (team members without a technical background) were able to be actively involved in the design of the serious game. It also allowed the team to make the development process much more iterative and at the same time shorten the overall development time.

The chapter is structured as follows. Section 25.2 provides an overview of related work. Section 25.3 explains the main principles of the ATTAC-L language. Section 25.4 discusses the different modeling concepts available in the language. In Sect. 25.5, the controlled natural language syntax of ATTAC-L is provided and explained, and in Sect. 25.6, we show how the syntax is mapped onto a graphical notation to turn the language into a graphical modeling language. Section 25.7 demonstrates the use of the DSML for an example serious game. In Sect. 25.8, we explain how the designed pedagogy can be explicitly linked with the narrative. Section 25.9 elaborates on the different tools developed to support the ATTAC-L language. In Sect. 25.10, we present our experiences in using the ATTAC-L tool in the context of the development of a serious game against cyber bullying. Finally, Sect. 25.11 presents conclusions and future work.

## 25.2 Related Work

In this section, we discuss related work that deals with the modeling and authoring of story-based serious games and compare these with our own work. Various authoring tools have been created for designing story-based serious games, such as interactive digital storytelling tools, e.g., StoryTech (Göbel et al. 2009), <e-Adventure> (Torrente et al. 2008), EDoS (Tran et al. 2010), and StoryBricks (StoryBricks 2014). In addition, several DSMLs have been developed and used for the same purpose, e.g., WEEV (Marchiori et al. 2003), Inform (Nelson 2006) and GLiSMo (Hirdes et al. 2012).

The 80Days project aims to establish a generic theoretical basis for immersive storytelling merged with cognitive, motivational and emotional aspects of learning processes. The StoryTec authoring tools (Göbel et al. 2009) were extended in the context of the 80Days project to enable the specification of adaptation and personalization aspects for targeted digital educational games. Nonetheless, the Story Editor tool is still using the same visual language that consists of story units (i.e., scene and complex scene visualized as rectangles) and transition between the different connected units that are visualized as arrows. There is also the possibility to create scenes that are not connected to each other. Such scenes will be selected during the runtime based on the adaptation mechanism. The author can define the expected time that the learner will stay in a scene. Furthermore, the author could identify the skill, tasks and goals to be achieved in the scene. StoryTec does allow to create relationships between different parts of the story and the associated learning objectives and goals, however direct links between high-level pedagogical strategies and low-level game mechanics cannot be established as we do in our approach. Also, in contrast to our DSML, support for code-generation out of story models is not provided.

<e-Adventure> (Moreno-Ger et al. 2008) is a platform for designing adventure games of the point-and-click style that are mostly used for educational purposes. The goals of the platform it is to enable people to create games without the necessity of possessing programming skills. For this purpose, <e-Adventure> provides an authoring tool (Torrente et al. 2008) which includes a mechanism for creating characters by importing photos of individual characters taken from various angles. Furthermore, the tool also includes mechanisms for creating items, conversations and cut scenes, as well as a mechanism for importing pictures that will represent the scenes of the game. As such, the story of the game is basically represented as a sequence of scenes with the characters of the game positioned in them. The player

of the game will interact with each scene by clicking on specific active parts defined by the designer to trigger actions. The relationships between the scenes are defined as connections represented by lines in the authoring tool. The story of the game is then narrated to the player through pieces of text or audio fragments. In contrast to our approach, <e-Adventure> is a user-oriented toolset for creating educational games, rather than a DSML. This makes the <e-Adventure> tool more dependent on its targeted game environment and limits the end-user to the creation of games of the point-and-click genre. This type of games only offers limited support for the kind of behavior change that we targeted in the Friendly-ATTAC project. Our language can be used with a broader range of game types and platforms for educational game platforms.

EDoS or Environment for the Design of Serious Games (Tran et al. 2010) is an interactive authoring environment for serious games that also aim to integrate educational strategies into the narrative by explicitly linking pedagogical design principles to particular elements of the narrative. Its purpose is similar to ours: to help an interdisciplinary team in designing a serious game by offering a number of standardized steps, starting with the formulation of pedagogical objectives and continuing all the way up to the point of elaborating a scenario and modeling user interactions. The outcome of following these standardized steps is "a structured scenario that will be automatically executed by an engine" (Tran et al. 2010, p. 393). EDoS focuses on the reusability of available components of different granularity and the creation of serious games for teaching engineering skills. The design process of EDoS builds on three models. The first one is a model of the targeted pedagogical objectives, e.g., professional competences for an engineer. The second model relates pedagogical objectives and pedagogical activities in order to construct pedagogical scenarios for serious games. These scenarios are created using an adapted version of the Instructional Management Systems – Learning Design language (IMS-LD) (Koper and Olivier 2004) which only describes the pedagogical content of the serious game. The third model helps to include the entertaining elements, i.e., the task model that describes the screens with which the users will interact. In contrast to our approach, EDoS relies on a specific learning design, namely IMS-LD and thus provides limited flexibility in this respect.

The StoryBricks framework is an interactive story design system that was discontinued in 2014 (StoryBricks 2014). It provides a visual language based on the visual programming language Scratch (Resnick et al. 2009) designed by the MIT lab. Without the need for programming skills. The designers do not need programming skills to edit the characters in the game and the artificial intelligence of the game that drives the characters. The designers can set up characters' inventory, needs and emotions by using so-called story bricks. The bricks can also be used to specify what is to be done at certain points in the game. This way, an interactive scenario is modeled in an implicit way by defining a set of rules expressing which events should be evoked under what conditions. This enables interaction between the characters in the game without being programmed explicitly. The StoryBricks approach allows a great deal of flexibility in defining the rules for the game logic, but a story cannot be modeled explicitly. A user experiment performed in the ATTAC-L project (see Sect. 25.3) showed that an event-based approach like this would be less suitable for our target group (experts without programming knowledge). Our work has adopted the brick concept as basic building block for our language, but we require the designers to model the flow of the story explicitly. Moreover, we provide a mechanism to model the pedagogical aspects of games.

WEEV or Writing Environment for Educational Video Games (Marchiori et al. 2011) also proposes a DSML to model the narrative content of educational games. As a proof of concept, this DSML is added on top of <e-Adventure> . In WEEV, story modeling is based on an explicit representation of the interactions between the player and the virtual world by means of a state-transition diagram. To reduce the overall complexity WEEV has language constructs that help to organize the structure. Whereas WEEV uses a state-transition approach, we use a flow-based approach. As already mentioned, this decision was informed by the results of a user experiment that we performed. Moreover, we impose a strict separation between the specification of the narrative and the pedagogical aspects, while both aspects are interwoven in WEEV.

The GLiSMo language or Serious Game Logic and Structure Modeling Language (Hirdes et al. 2012) is specifically designed to model teaching methods directly into the game logic of an educational game. For this, it uses the concept of a serious game brick, i.e., a block representing a single atomic step that can be executed in the context of an educational game-environment. This can be related either to a logical or a pedagogical functionality of the game. The bricks have input- and output ports. The overall game logic is modeled by linking several bricks through these ports. This interlinking defines a temporal relationship and data flow between the bricks, giving the model a data flow-based structure. An abstraction mechanism is provided in the form of a serious game composite which is used in the same way as a brick but encapsulates one or more interlinked bricks. As a consequence, the composite provides a way to organize more complex models. Our research, developed in parallel, uses similar principles. We have opted, however, for an explicit flow-based structure that only requires designers to define temporal relationship between game moves. Pedagogical aspects are expressed using annotations, which allows for a better separation of concerns (SoC) (Hürsch and Lopes 1995).

Inform (Nelson 2006) is a toolset targeted toward professional narrators. It allows them to create interactive fiction (e.g., adventure games). Since version 7, Inform includes a DSML to define all aspects of an interactive fiction, including setting (i.e., scene), character setup, and story flow. The DSML uses a CNL. In contrast to Inform, we opted for a graphical language as most DSMLs do. Also, our DSML does not allow designers to define aspects such as environment settings and low-level implementation aspects. Instead, it focuses on the specification of the narrative and the educational aspects, thereby reducing the complexity and increasing the understandability. In our approach, complementary tools specify these kinds of aspects.

## 25.3 Principles of the Language

### *25.3.1 Domain-Specific Modeling Language*

ATTAC-L is a Domain-Specific Modeling Language (DSML). A domain-specific language is usually a small language, dedicated and restricted to a particular domain (Deursen et al. 2000). It provides abstractions that make it easier and less time consuming to specify solutions for a particular class of problems in the domain. The final system is then generated from these high-level specifications (i.e., models) (Kelly and Tolvanen 2008).

By using suitable abstractions and building on the vocabulary of the problem domain, a domain-specific language enables domain experts to understand, validate and often even develop specifications autonomously. Luoma et al. (2004) showed that DSMLs require less modeling work and that this modeling work could often be carried out by persons with limited programming experience. They found a clear productivity increase.

### *25.3.2 Controlled Natural Language*

Various authors have presented arguments in favor of using a DSML for modeling (serious) games (e.g., Dobbe 2007; Furtado and Santos 2006; Guerreiro et al. 2010; Marchiori et al. 2011). However, for most DSMLs, the gap between the user's mental model and the syntax of the DSML is still big. For instance, Marchiori et al. (2011) is using state transition diagram principles. The DSMLs proposed by Dobbe (2007), Guerreiro et al. (2010), and Furtado and Santos (2006) are still more oriented towards game developers than towards experts with a non-IT background. Contrary to these approaches, our DSML uses a Controlled Natural Language (CNL) (Wyner et al. 2010), which is a strict and controlled subset of natural language. Using a CNL syntax for our DMSL provides an easy and human-readable, flexible and expressive way to specify the story of the game. This makes it significantly easier for people without programming knowledge to understand as well as to create models. In this way, collaboration within multidisciplinary teams can be better supported. Compared to the use of natural language, a CNL approach offers the advantage that it still allows for fully automatic processing of the specified models needed for our model-driven approach.

### *25.3.3 Flow-Oriented Modeling*

ATTAC-L's CNL provides the necessary means to model the narrative of a serious game. The story is specified as a number of interactive scenarios. A scenario is a flow-oriented specification of the different possible actions (called game moves) and choices in the narrative. The result is called a story model.

We have opted for a flow-oriented specification based on a small user experiment focused on determining which modeling approach was most convenient for people without a programming background. In this study, we compared three approaches: a state-based, a flow-based, and an event-based approach. The participants (7 males and 13 females between the age of 25 and 36, all without programming knowledge) were presented with scenarios using the three approaches. Inquiries were made about the ease of use, convenience, comprehensibility and the general preferences of the participants. The flow-based representation was clearly the most convenient one, followed by the rule-based approach, and the state chart, which was almost unanimously marked as the least favourite one.

### *25.3.4 Graphical Language*

A DSML is often graphical in nature, i.e., using visual notations. Well-designed visual notations are known to be more accessible for people without a technical background as they allow them to grasp large amounts of information more quickly than large listings of textual specifications (Moody 2009).

With this in mind, ATTAC-L also uses graphical notations. This means that the natural language sentences used to describe the narrative of a serious game (and expressed in the CNL syntax of ATTAC-L) are expressed using visual notations instead of plain text. The main graphical construct is the 'brick' concept, adopted from Storybricks. Bricks are used for a wide range of things, from modeling the stories by expressing narrative events or specifying the control of the interactivity, to specifying the overall story flow or even the pedagogical aspects of the serious game.

### *25.3.5 Open Narrative*

The CNL syntax used for ATTAC-L provides a mechanism for creating open narratives. This means that the CNL syntax does not required every involved game entity to be directly identified while the actions are specified. Instead, the syntax allows for the specification of interactions between highly generic described game entities, based on type, property, state or a combination of these. During gameplay, a specific instance of a narrative conforming to this general description is generated, resulting in a slightly different progression of the game narrative on each run. The advantage of this is that the game can be played several times without becoming too predictable.

## 25.4 Modeling Concepts

This section discusses the different modeling concepts available in the language for modeling a story-based serious game. We first describe the modeling constructs for specifying the game narrative. Next, we outline the mechanism for specifying and integrating other game aspects such as pedagogical aspects into the story model.

### *25.4.1 Modeling Concepts for the Game Narrative*

#### 25.4.1.1 Game Moves

To model a narrative, we use the concept of a game move. Lindley (2005) defines a game move as a single step or turn taken by any player at any time during the execution of a game. However, in the context of ATTAC-L, a game move represents one individual step in the game narrative, performed either by the player or a non-playable character (NPC).

Modeling a narrative entails defining game moves and linking them to each other to denote their relative order in the flow of the story. Game moves are specified using the CNL syntax (see Sect. 25.5 for its definition).

#### 25.4.1.2 Bricks

Because we are using a CNL syntax, game moves are expressed as natural language sentences. But as ATTAC-L is a graphical modeling language, the game move sentences are composed in a graphical way by connecting bricks (Van Broeckhoven and De Troyer 2013) (see Fig. 25.1). In the context of a game move, a brick corresponds to a meaningful unit in the story: an act to be performed, a tangible object that can perform or undergo the act, a state, or a value. A brick is graphically represented as rectangle containing a word or word-group (see Fig. 25.2a). Bricks must be interconnected according to the rules of our controlled natural language (see Sect. 25.5) (Van Broeckhoven et al. 2015b). The result is a construct that reads as a simple sentence and denotes a game play activity (see Fig. 25.1). The bricks used to construct the game moves are so-called game-move-bricks.

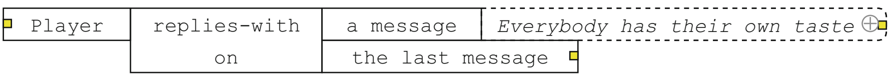


**Fig. 25.1** A graphical representation of a game move. This representation reads as follows: "Player replies-with a message 'Everybody has their own taste' on the last message" and is composed of 5 bricks

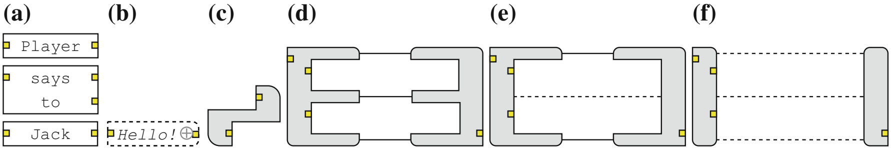


**Fig. 25.2** Several types of bricks. (**a**) Game-move. (**b**) Value. (**c**) Sequence. (**d**) Choice. (**e**) Order ind. (**f**) Concurrence

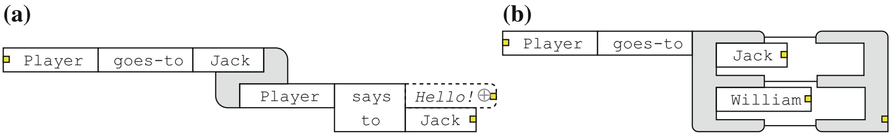


**Fig. 25.3** Connecting bricks to form storylines and story-flows. (**a**) Two game moves in sequence. (**b**) A choice between two game moves

For composing game moves into a narrative, i.e., expressing their relative order, we provide the following common control structures: sequence, choice, and concurrency. Sequences are used to signify that game moves follow each other, thus resulting into storylines. Choice is used to express alternative storylines, i.e., branching. Concurrency is used to indicate that storylines should be performed in parallel. In addition, ATTAC-L provides an extra control structure to increase the language's expressiveness, called 'order independence'. This control structure allows modelers to specify that different storylines must all be performed regardless of the order. To avoid any link with programming constructs, the control structures are also visually represented by bricks, called control-bricks. Figures 25.2c–f show the graphical representations of the control bricks. Figure 25.3 illustrates their use.

A sequence of game moves and/or control bricks is called a story-flow. Note the difference between a storyline and a story-flow: the former only involves sequences of game moves, and thus literally represents a single linear 'line' of progression of the narrative, while the latter may also include control structures, i.e., choice, concurrency and/or order independence, and thus can express different alternatives of how a story could evolve during a performance.

Next to the regular game-move-bricks and control-bricks, there are also two other types of bricks: scenario-bricks and annotation-bricks associated respectively with the modeling concepts scenarios and annotations. These are explained in the next sections.

#### 25.4.1.3 Scenarios

It is not uncommon that stories result in vast models with rich and complicated story-flows. To provide a structuring mechanism for such story-flows, the concept

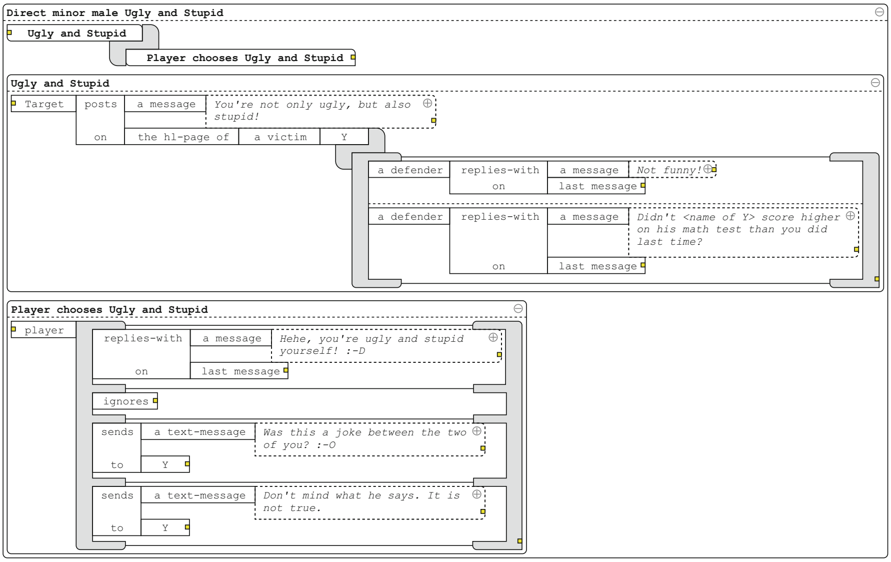


**Fig. 25.4** Example storyline model divided into scenarios

of scenarios was introduced. It allows for the decomposition of a story model into smaller logical units. The principle of using scenarios is analogous to the structuring of theater and film scripts whereby the story is divided into separate scenes. In contrast to scenes in theater and films scripts, scenarios in ATTAC-L can be reused in various places throughout the story model. To accommodate reusability, scenarios are separately defined and given a name that acts as a placeholder for the content of a scenario in the story-flow. The scenarios are used in a story-flow by means of a scenario reference-brick or shortly scenario-brick. Upon encountering a scenario-reference-brick during interpretation of a story model, the content of the referenced scenario is inserted as if it was an integral part of the story-flow. Note that scenarios can also be nested inside other scenarios.

An example of a simple story model is given in Fig. 25.4. The example depicts a scenario from the Friendly ATTAC serious game named ‘Direct minor male Ugly and Stupid’. In this scenario, the player is expected to react adequately on a cyber bullying situation. The scenario is composed of two nested sub-scenarios: one in which the actual bullying situation occurs (‘Ugly and Stupid’ defined in the middle of the figure) and another in which the possible reactions of the player are listed (‘Player chooses Ugly and Stupid’ defined at the bottom of the figure). The actual scenario is defined by ‘chaining’ the two sub-scenarios. This is done by connecting the corresponding scenario-bricks with a sequence-brick (top of the figure). The two sub-scenarios are discussed in more detail in the Sect. 25.7.

### 25.4.2 Non-Narrative Modeling Concepts: Annotations

The concept of annotations enables the modelers to specify additional information to related parts of the story model, e.g., pedagogical relevant information and interventions, important gameplay aspects, or noteworthy visual and behavioral aspects of the environment (Van Broeckhoven et al. 2015a). The annotations add this information on top of the story model. This prevents that the information becomes too entangled with other aspects of the serious game. Pedagogical annotations, for example, enable the modelers to relate the pedagogical aspects of the serious game to the story-flow while maintaining a clear separation from the narrative content.

Annotations are represented graphically by means of small, square-like bricks called annotation-bricks. Annotation-bricks are "attached" to game moves or scenarios (depending on their type). The content of an annotation will pop up in the ATTAC-L tool when an annotation brick is clicked (described in more detail in the section Tool Support) (see Fig. 25.5 for an example).

Each annotation-brick contains an icon that indicates its type. The type of the annotation determines the structure of the content of an annotation. Currently, we distinguish between two main types of annotations. The first type are the pedagogical annotations (PA) which are used for specifying pedagogical aspects of

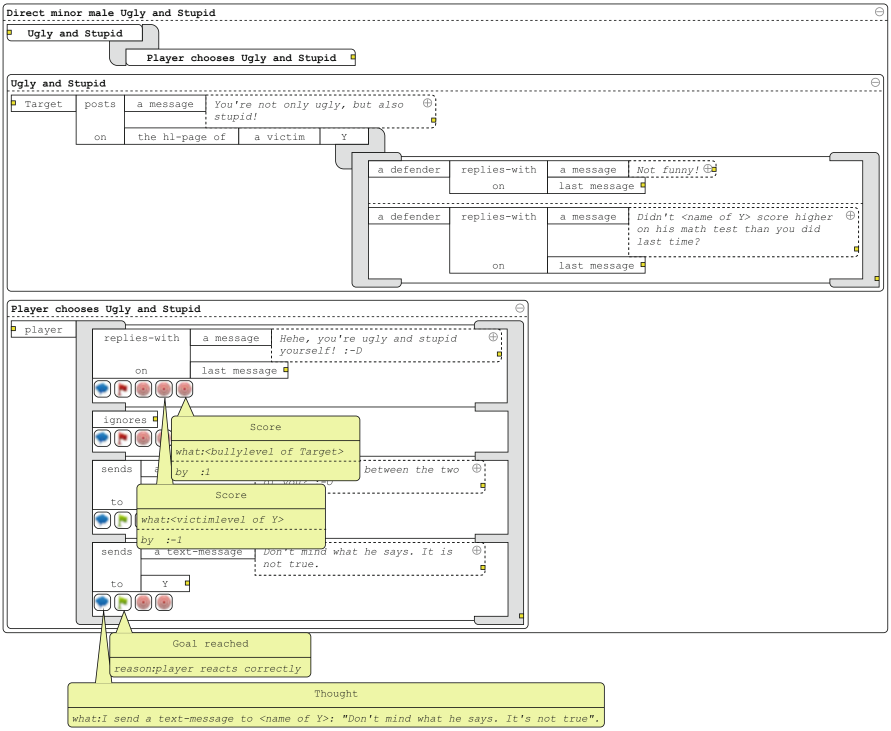


**Fig. 25.5** Annotated storyline model from Fig. 25.4

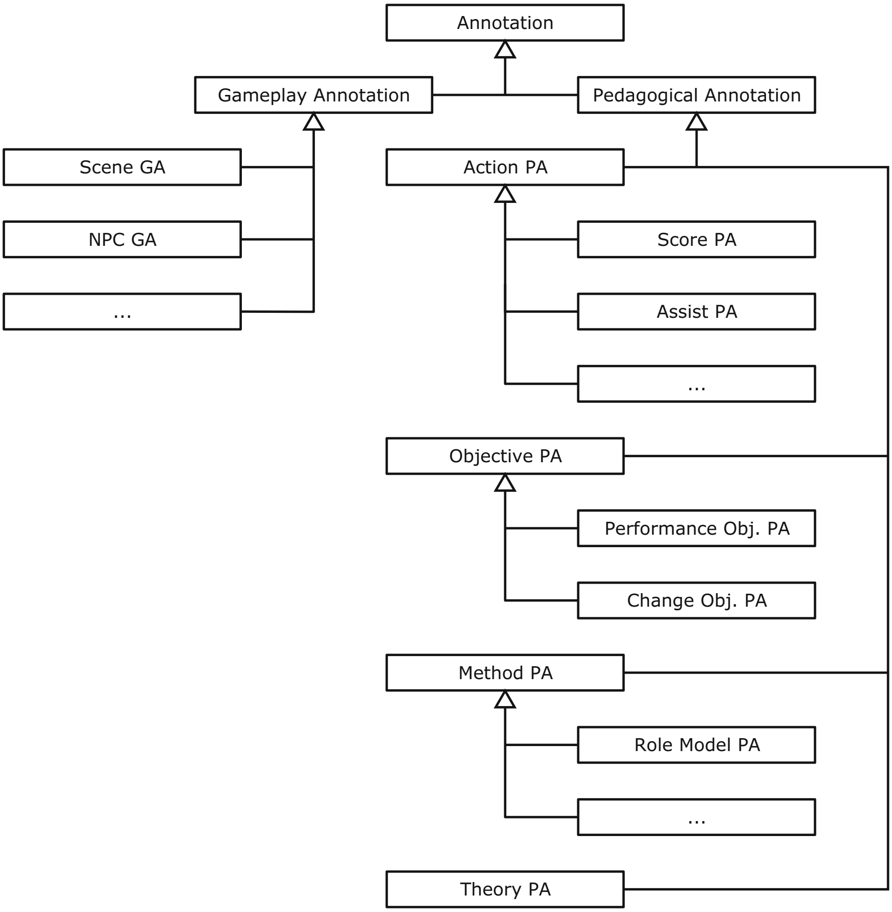


**Fig. 25.6** The annotation classification

the serious game. The second type are the gameplay annotations which are used for specifying aspects related to gameplay, such as the game environment (e.g., for indicating a change of the scene) and NPCs (e.g., emotions that should be expressed or behavior that should be displayed). Note that this annotation system is extensible in the sense that other types of annotations can be defined and used when needed. For instance, the language can be extended with annotations to indicate specifications related to the mode(s) of interaction. An overview of the current annotation classification system is given in Fig. 25.6.

For the purpose of this chapter, we concentrate on the PAs because of their specific relation to the domain of serious games. PAs are divided into action PA, objective PA, pedagogical theory PA, and method PA:

- Action PAs are used to specify pedagogic actions that should be performed at particular moments in the story, for instance: providing additional information, giving assistance or feedback. In other words, action PAs are concrete pedagog-

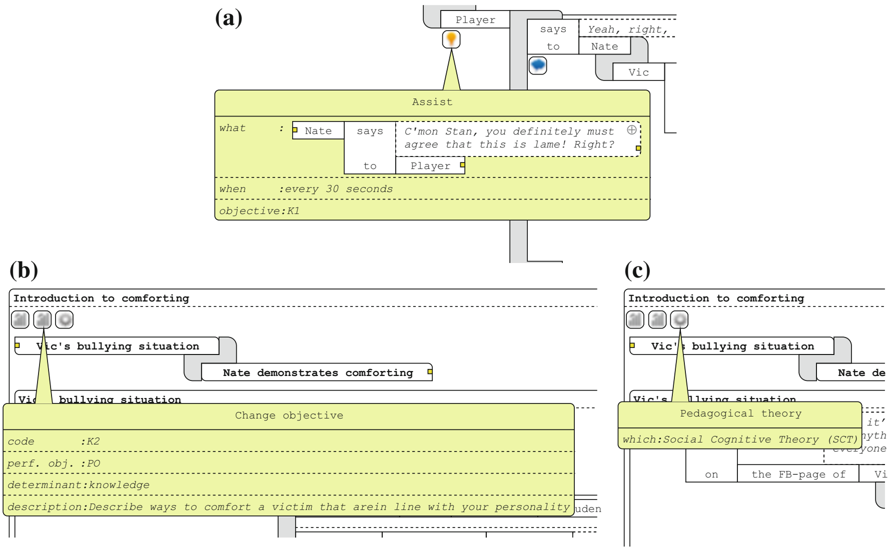


**Fig. 25.7** Several types of annotations (close-ups taken from Fig. 25.12). (**a**) Pedagogical action annotation. (**b**) Pedagogical objective annotation. (**c**) Pedagogical theory annotation

ical interventions. Action PAs are associated with a particular game move and indicate that these interventions should be performed simultaneously with the game move. See Fig. 25.7a for an example of an assist PA.

- Objective PAs are used to explicitly relate pedagogical objectives, such as learning goals or behavioral change objectives, to scenarios or parts of the story-flow. An example of such an objective would be 'to know the multiplication tables of 1 to 10' or 'to understand the impact of cyber bullying'. They can only be associated with scenarios. See Fig. 25.7b for an example of an objective PA.
- Pedagogical theory PAs are used to specify the underlying pedagogical theory that is applied in order to achieve the pedagogical objectives (e.g., behaviorism, constructivism, …). These PAs are attached to a complete story model or a scenario. See Fig. 25.7c for an example of a theory PA.
- Method PAs are used to specify the particular pedagogical methods used to reach particular pedagogical objectives in the story or the scenarios. Examples of such methods are drill & practice, problem-based learning, or learning-by-doing. Since many different methods are possible – each with different characteristics – this annotation type is an abstract one (cf. abstract class in UML), i.e., we cannot define all of its properties. Concrete subtypes can be defined for different methods. For instance, the role-modeling PA has been defined for the 'modeling' or 'observational learning' principle used in the Social Cognitive Theory (SCT) (Bandura 1991). Similar to Objective and Pedagogical PAs, Method PAs are also attached to scenarios.

## 25.5 ACE-Based Syntax

As motivated in the introduction, we use a CNL for the syntax of the game moves. The CNL used is a subset of Attempto Controlled English (ACE) (Fuchs et al. 1999). We opted for ACE because its expressiveness is well suited for our purpose and because it has a solid foundation, namely: first order logic. ACE expressions are formulated like plain English sentences written in the third person singular simple tense. They describe logical terms, predicates, formulas and quantification statements. Furthermore, ACE defines two word classes: function words (determiners, quantifiers, negation words, ...) and content words (nouns, verbs, adverbs and prepositions).

The use of ACE for the syntax of game moves implies that game moves are expressed in 3rd person simple tense. This implies that narratives are modeled as if they were told from a narrator's point of view. Similar to ACE, the ATTAC-L syntax distinguishes between function words and content words. Our set of content words consists of nouns, verbs, and adjectives. These correspond respectively to entities, acts, and states in the story-flow. Our set of function words consists of determiners, negation words, pronouns, and the copula 'to be'. Unless otherwise specified, words are always written in lower case letters. Also in accordance with ACE, sentences are always composed of two main parts: a subject followed by a predicate. The former describes the entity that invokes the action and is called a noun phrase, while the latter describes the action itself and is expressed as a verb phrase.

The overall syntax for game moves in Extended Backus Naur Form (EBNF) (ISO 1996) is as follows:

```
game-move          : subject predicate;
subject            : noun-phrase;
predicate          : verb-phrase;
```

In the following sections we describe the formal syntax for the different types of phrases. In the EBNF excerpts, the formal definitions of some general expressions have been omitted for simplicity. This includes rewrite-rules for the most basic elements that are part of a game move expressions, such as those for noun, pronoun, verb, value etc. They amount to regular expressions for words, numbers, quoted strings, and more. The following listing summarizes those elementary parts and describes how they should be interpreted:

- **noun**: a lowercase word. Semantically, this can be any *singular common noun* as determined by the set of content words.
- **nouns**: a lowercase word. Semantically, this can be any *plural common noun* as determined by the set of content words.
- **proper**: a lower or uppercase word, but always starting with an uppercase character. It may contain dashes ('-'). Semantically, this *may* refer to predefined proper nouns contained in the set of content words.
- **adjective**: a lowercase word. Semantically, this can be any *adjective* contained in the set of content words.

- **verb**: a lowercase word. Semantically, this can be any *3rd person singular verb* as determined by the set of content words.
- **passive-verb**: a lowercase word. Semantically, this can be any *past participle form of a verb* as determined by the set of content words.
- **value**: any of:
  - quoted string
  - number
  - sequence of values separated by comma (‘,’), enclosed by brackets (‘[]’)
  - sequence of key-value assignments separated by comma (‘,’), enclosed by braces (‘{}’)
- **determiner**: the set of all supported determiners as defined by the set of function words (‘a’, ‘an’, ‘one’, ‘1’, ...)
- **quantifier**: the set of all supported quantifiers as defined by the set of function words (‘some’, ‘all’, ‘two’, ‘2’, ...)
- **copula**: ‘is’ or ‘are’
- **preposition**: the set of all supported quantifiers as defined by the set of function words (‘in’, ‘to’, ‘out’, ‘until’, ...)

### *25.5.1 Noun Phrases*

The simplest form of a noun phrase is a proper noun that refers to an entity by means of a name. Nouns always start with an upper case letter and may contain upper and lower case letters or digits (e.g., ‘X1’, ‘John’). Spaces are not allowed, but hyphens can be used to form word-groups (e.g., ‘Mr-Smith’). The proper noun ‘Player’ is reserved to refer to the player or the character that the player is controlling.

A noun phrase can also refer to a game entity in an indirect way by means of a countable common noun. In this case, a common noun is preceded by a determiner or a quantifier, for instance ‘a door’, ‘2 doors’, ‘some persons’, ‘all keys’. This type of noun phrase can be used to refer to a single entity (e.g., ‘the house’, ‘a door’, ‘some person’, ‘one key’) or to multiple entities (e.g., ‘2 doors’, ‘some persons’, ‘all keys’). This type of noun phrase is used to refer to one or more entities in a generic way. This means that on different ‘runs’ of the story-flow, different entities conforming to this noun phrase could be selected. This allows narrative designers to create less predictable stories.

Variables are a way to assign a proper name to a countable common noun phrase, for instance ‘a person Mr-X’. In this case, the proper name can be used to refer to the same entity in subsequent game moves. This corresponds to an inline and implicit declaration of a variable in programming languages. For people without programming knowledge, this approach is more natural and likely easier to grasp than the use of explicit variable declarations.

Adjectives can be used to make a countable common noun phrase more specific. As such, the set of entities out of which a specific noun (i.e., game entity) is selected at run-time can be narrowed down. Adjectives can be positive, superlative or conjoined (e.g., 'the last person', 'two highest trees', 'a sad and angry person').

Genitives are used to refer to nouns that have a possessive association with another noun. Genitives are constructed by appending the noun phrase of the possessor to the noun phrase of the possession using the preposition 'of', for example 'the back-pack of Jack' or 'two items of a person'. Note that in Standard English, the use of the preposition 'of' might sound odd in some cases (e.g., 'two apples of a tree' as opposed to 'two apples from a tree'). Nonetheless, we have refrained from introducing extra prepositions in order to keep the syntax of ATTAC-L as simple as possible.

Values (text, numbers, lists and parameter-value tuples) can be used as noun phrases when their noun can be deduced from the context of the game move. For example, when the game move expresses a speech action, the action can only involve a text-value. The type of a value can be specified directly by prepending a common noun (e.g., 'a message "Hello!" ').

The formal syntax for the noun phrases is as follows:

```
noun-phrase              : proper
                         | value-noun-phrase
                         | common-noun-phrase
                         | common-noun-phrase , 'of' ,
                             sing-common-noun-phrase ;
value-noun-phrase        : value
                         | determiner noun value ;
common-noun-phrase       : sing-common-noun-phrase
                         | mult-common-noun-phrase ;
sing-common-noun-phrase
                         : determiner , [ adjective ], noun ,
                             [ proper ];
mult-common-noun-phrase
                         : quantifier , [ adjective ], nouns ,
                             [ proper ];
```

### 25.5.2 Verb Phrases

A verb phrase corresponds to the predicate of a sentence and describes the actual activity performed in a game move. Generally, a verb phrase starts with the conjugated verb. Depending on the type of verb used, direct and indirect passive objects can be included in the verb phrase. While an intransitive verb stands on its own (e.g., 'to wait'), a transitive verb involves only one direct passive object (e.g., 'to see something '), whereas a di-transitive verb involves both a direct and indirect passive object (e.g., 'to give something to somebody '). Some verbs can also be associated with a preposition. In this case, the combination verb-preposition is considered as a whole and is written as a hyphenated combination (e.g., ‘X walks-to Y’ or ‘X looks-at Y’).

The formal syntax for the verb phrases is as follows:

```
verb-phrase          : verb
                     | verb , noun-phrase ,
                         [ preposition , noun-phrase ];
```

### 25.5.3 Adjective Phrases

It is possible to use an adjective phrase as part of a verb phrase. Similar to verbs, an adjective phrase can be intransitive (e.g., ‘happy’, ‘sad’) or transitive (e.g., ‘angry with somebody’ or ‘afraid of something’). In the latter case, the adjective is always associated with a preposition and must be written as hyphenated combination (e.g., ‘angry-with X’).

The copular verb ‘to be’ serves a special purpose. Copular verbs establish a link between the meaning of a predicate of the sentence and its subject. This means that they can be used to set a state for the subject. In order to do so, the copular verb is suffixed by an adjective phrase, for example ‘X is happy’ or ‘X is angry-with Y’.

The formal syntax for the adjective phrases is as follows:

```
adjective-prase      : adjective , [ noun-phrase ];
```

The formal syntax for the verb phrases, also taking adjective phrases into account is as follows:

```
verb-phrase          : verb
                     | verb , noun-phrase ,
                         [ preposition , noun-phrase ]
                     | copula , [ 'not' ],  adjective-prase;
```

### 25.5.4 Special Sentence Structures

Some special structures are added to provide the modeler with extra flexibility or expressive power. The phrases ‘there is’ and ‘there are’ are introduced to allow the modeler to explicitly declare variables. These phrases are followed by a noun phrase with a variable (e.g., ‘there is a person Mr-X’ or ‘there are two persons The-Johnson-Brothers’). The modeler can express any sentence containing a transitive or di-transitive verb phrase in a passive voice. A passive voice sentence uses the copular verb ‘to be’ in combination with the past participle tense of the verb. The subject and the direct passive object are then swapped (e.g., ‘X steals an item of Player’ becomes ‘an item of Player is stolen by X’). This option increases flexibility by allowing the modeler to create sentences where the character that performs the action is unknown, i.e., when no subject would be present in the active equivalent of the sentence, for instance ‘an item of Player is stolen’. The formal syntax for the special sentences is as follows:

```
passive-verb-phrase  : copula , passive-verb ,
                          [ 'by', noun-phrase ]
                     | copula passive-verb noun-phrase ,
                          [ 'by', noun-phrase ];
definition           : 'there', 'is', determiner, noun, value,
                          proper
                     | 'there', 'are', quantifier, nouns, value,
                          proper;
```

## 25.6 Mapping the Syntax to Bricks

The CNL-based game moves are expressed by means of our graphical language constructs, i.e., bricks. The game-move-bricks contain words or word-groups and are connected to each other in accordance with the syntax rules of the language.

A game-move-brick containing a noun phrase is called a noun-brick and refers to a tangible entity, i.e., an object, an NPC or a player (see Fig. 25.8a for examples).

Adjectives used for noun-phrases are contained in the noun-brick because they are part of the noun-phrase (see Fig. 25.8b for an example). Adjectives used as adjective phrases are placed in an adjective-brick followed by a noun-brick in case it is a transitive adjective phrase (see Fig. 25.8c).

To introduce a variable, an extra noun brick containing the proper name of the variable is joined at the end of the noun-brick (see Fig. 25.8d). This allows the variable to be used independently in subsequent game moves.

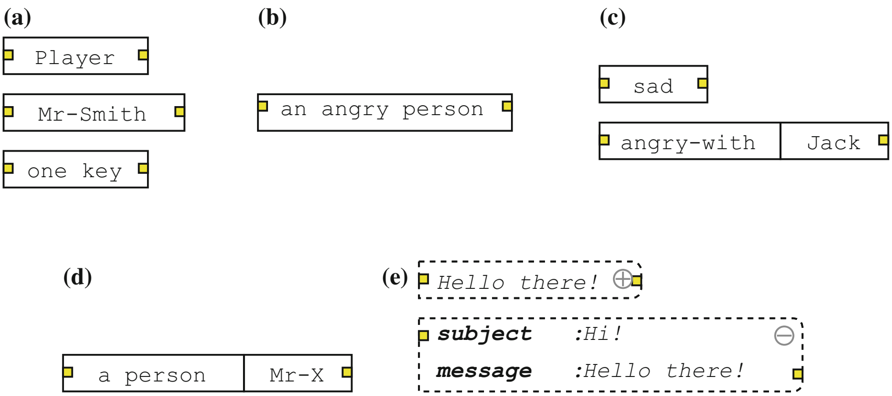


**Fig. 25.8** Noun and adjective phrases

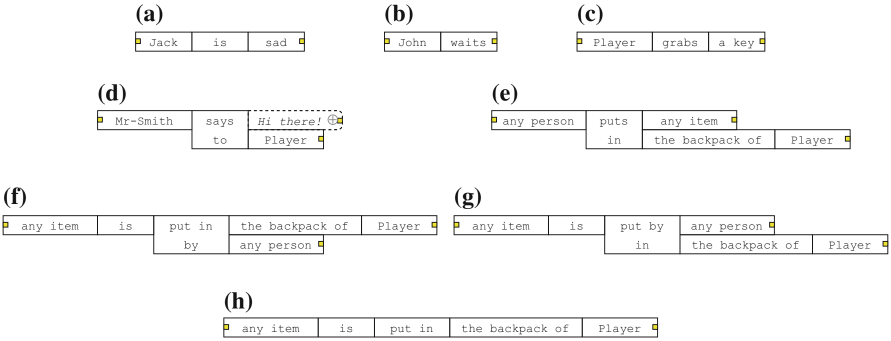


**Fig. 25.9** Verbs connecting noun and adjective phrases, forming game moves

Values are represented by value-bricks (see Fig. 25.8e) and can only be connected to the end of a game move. Visually, they are delineated by a dotted line, whereas regular game-move-bricks have a solid border. As values can be text and numbers, but also lists and parameter-value tuples, value-bricks should support the specification of complex data. Therefore, value bricks can contain multiple lines or key-value combination (see second example in Fig. 25.8e).

A game-move-brick containing a verb is called a verb-brick. It connects to noun-bricks and/or adjective-bricks. In the case of a di-transitive verb, the associated preposition serves as an extra connecting point for the indirect passive object (see Fig. 25.9 for illustrations of the most common cases).

As explained, game moves containing a transitive or a di-transitive can also be expressed in a passive form (Fig. 25.9f represents the passive equivalent of Fig. 25.9e). In passive sentences, the placements of the indirect passive object and the direct passive object (i.e., the original subject) can be interchanged (Fig. 25.9f and g can be used interchangeably to represent the same game move). In some cases, the ‘by’ part of the sentence can be omitted (see Fig. 25.9h). The subject of the game move is then assumed to be any NPC.

## 25.7 Overall Example

To illustrate the use of the language for a more elaborated narrative, we provide fragments from the serious game developed in the context of the Friendly ATTAC project. The overall story of the game is composed out of several sub-stories, which are all modeled as separate scenarios. Annotations are used to associate several performance metrics to the scenarios that are tracked as the player progresses through the game. Based on the player’s progression, the overall game narrative is adapted by the runtime environment to the player’s performance.

The first example is a scenario in which the player is expected to react adequately on a cyber bullying situation (introduced earlier in Sect. 25.4.1.3 see Fig. 25.4). The scenario is composed of two nested scenarios: one in which the actual bullying situation occurs ('Ugly and Stupid'), and another in which the possible reactions of the player are enlisted ('Player chooses Ugly and Stupid'). Both sub-scenarios are 'chained' by connecting the corresponding scenario-bricks with a sequence-brick (at the top of Fig. 25.4).

The 'Ugly and Stupid' scenario starts with a bully (referred as 'Target') posting an insulting message on the in-game social profile page of some NPC, referred as 'a victim Y'. The noun 'a victim' indicates that any in-game character that fits the role of a victim could be selected (at runtime) to fulfill the role of the targeted NPC. The pronoun 'Y' is used to name this selection. This allows the modelers to refer to the selected character further on in the scenario simply by means of 'Y'. The use of this construct ('a victim Y') allows the game to select different NPCs in each run. This will reduce predictability and increase the replay value of the game.

Next, two other characters (defenders) express their disapproval of the message that has been posted. The noun 'a defender' has a similar purpose as the victim noun, but in this case, at runtime the game will select NPCs that are inclined to react against bullying situations. The adjective 'last' in 'the last message' allows the modelers to refer to the last specified entity indicated by the noun, here: the message that was posted by Target. Both game moves are combined with an order-independence structure, indicating that both should occur, but the order is unspecified because it is irrelevant.

The 'Player chooses Ugly and Stupid' scenario specifies the choices that will be presented to the player. The use of 'Player' as subject indicates that for this game move, interaction by the player is required. In this case, the player has the choice between 4 options: insulting the bully, ignoring the situation, or two ways of comforting the victim.

## 25.8 Linking Narrative and Pedagogy

During the design of a serious game, designers are not only faced with the challenge of creating a compelling narrative, but also with the additional challenge of incorporating suitable learning theories and pedagogical methods into their narratives in order to ensure that the game can achieve the defined objectives. To create the link between the story model and the pedagogical methods developed for the serious game, we have introduced the concept of annotations, in particular: a collection of PAs (for the overview of the PA types, see Sect. 25.4.2).

It is not possible to provide a single recipe for integrating an instructional design strategy into a serious game as each learning theory and pedagogical method has its own unique principles. In Van Broeckhoven et al. (2016), a general description of the process of linking a game's narrative with pedagogical theories and methodological design strategies has been elaborated and illustrated with two specific cases, namely: Social Cognitive Theory (SCT) (Bandura 1991) and the Intervention Mapping Protocol (IMP) (Bartholomew et al. 2011).

In this chapter, we illustrate how narrative and pedagogical aspects have been linked in the serious game developed for the Friendly ATTAC project. To come to a well-grounded and effective game, the Friendly ATTAC team used the Intervention Mapping Protocol (IMP). IMP has been developed to aid in the systematic planning and design of behavioral change programs focused on health issues. IMP investigates the behaviors that can help to reduce the targeted problem. These behaviors are set forth as performance objectives. Furthermore, change objectives must be established. These express what needs to be changed in order to achieve the performance objectives. The change objectives present the basis for the development of the actual pedagogical interventions in the serious game.

An example of a performance objective for the cyber bullying program developed in the Friendly ATTAC project is: 'always comfort the victim'. For this performance objective, the following change objective was defined: 'Recognize that by comforting the victim, you are making the victim feel better'.

To illustrate how the linking is achieved, we use the story model given in Fig. 25.10. The scenario that we use here focuses on the performance objective 'always comfort the victim'.

To specify which part of a story model is dealing with a particular performance objective, we use a special objective PA called a performance objective PA. This type of annotation is associated to a scenario and has a parameter to state the performance objective. Figure 25.10 shows an example of a performance objective PA. The performance objective is 'always comfort the victim'. In this example, the scenario is divided into two sub-scenarios, each dealing with one or more change objectives.

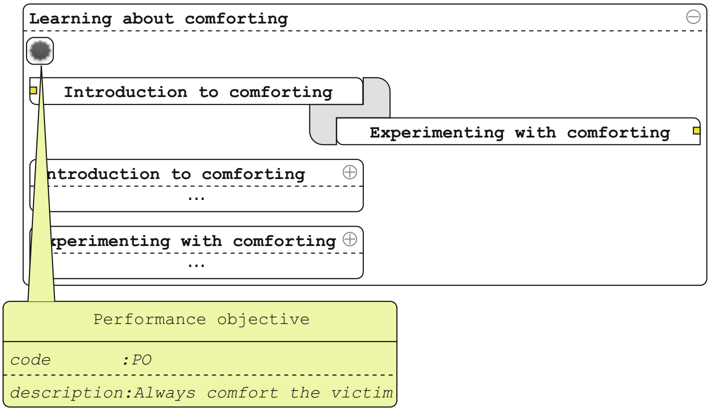


**Fig. 25.10** A scenario with a performance objective 'always comfort the victim' and two sub-scenarios (both detailed in Figs. 25.11 and 25.13)

To indicate with which change objectives the sub-scenarios are dealing, the scenarios are annotated with another kind of objective PA called change objective PA. This type of annotation has parameters to refer to the related change objective, to its encompassing performance objective, and to the determinants it is expected to change. The parameters also include a description (for documentation purposes). The sub-scenarios of the scenario 'Learning about comforting' used in Fig. 25.10 are 'Introduction to comforting' (elaborated in Fig. 25.11, fully annotated in Fig. 25.12) and 'Experimenting with comforting' (elaborated in Fig. 25.13, fully annotated in Fig. 25.14). The first one is annotated with change objectives related to the determinant 'knowledge'. This implies that the scenario should contain intervention methods specifically tailored to help increase the player's knowledge about comforting a victim. The second sub-scenario focuses on the determinants 'outcome expectations' and 'perceived social norms' and has two change objectives. This sub-scenario should thus include intervention methods that affect these determinants with the aim of achieving the change objectives.

Intervention methods identified with the help of IMP can be embedded in a story-flow in two ways: (1) as game mechanics that are complementary to the story-flow, or (2) as events expressed directly in the story. In order to express that an intervention method is operationalized through game mechanics, action PAs are used. To express the link with the change or performance objective, an action PA includes an argument that denotes the targeted objective. In Fig. 25.14, a score PA (special kind of action PA) is used to express that a scoring mechanism is used as an intervention method for achieving the change objective 'Sn1: Recognize that your friends expect you to comfort or provide advice to the victim'. Similarly, the same figure uses an assist PA (special kind of action PA) to help achieve the change objective 'Oe1: Expect that by comforting the victim, he/she will feel better'. This annotation expresses that at this point in the story-flow some assistance must be provided when the player takes too long to make a choice. As illustrated by the example, this can be done in the form of an NPC that makes the player aware that a victim will feel better when he comforts him, thus 'directing' the player to making the right choice.

## 25.9 Tool Support

Tool-support is provided for the creation of educational game scenarios using the ATTAC-L language. The developed toolset was used in the context of the Friendly ATTAC-project. The toolset consists of three major parts: a web-based graphical modeling tool for specifying educational game narratives, an export module for translating the model to executable code for the targeted game environment and a simulator for direct interpreting and fast-prototyping of the ATTAC-L models.

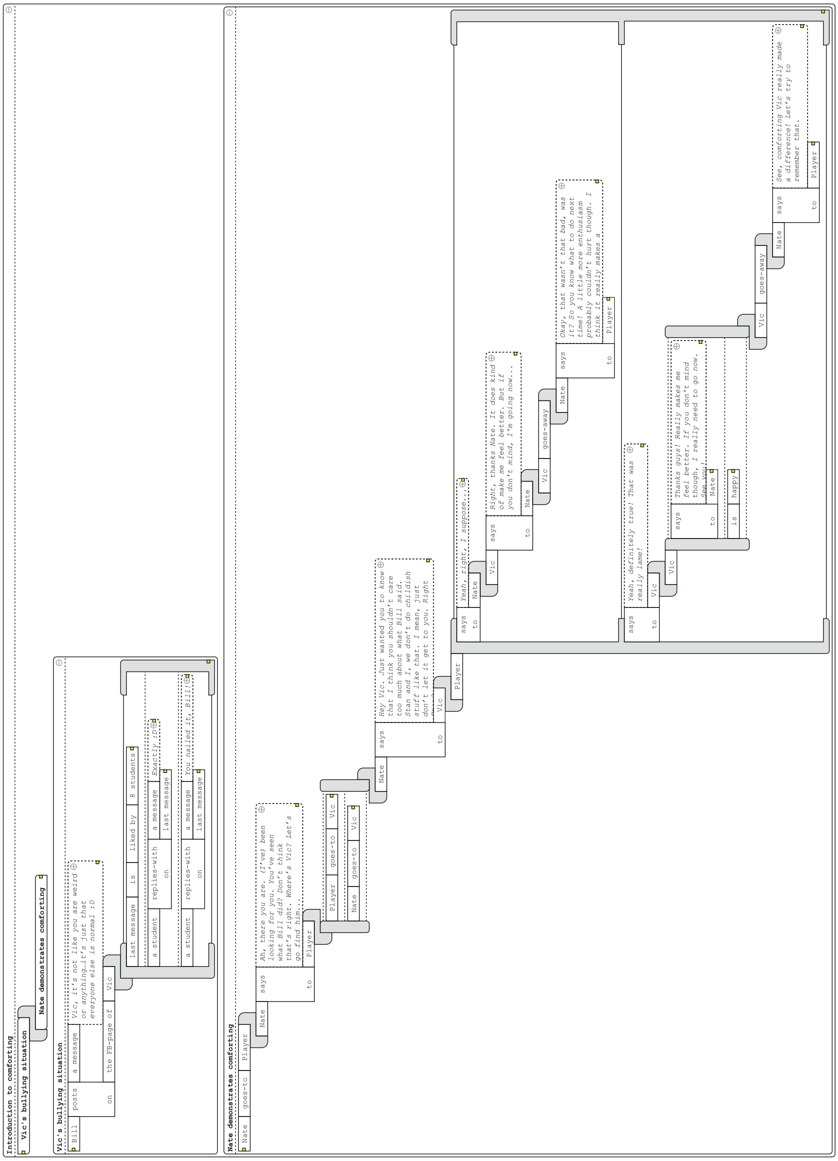

**Fig. 25.11** Example scenario 'Introduction to Comforting'

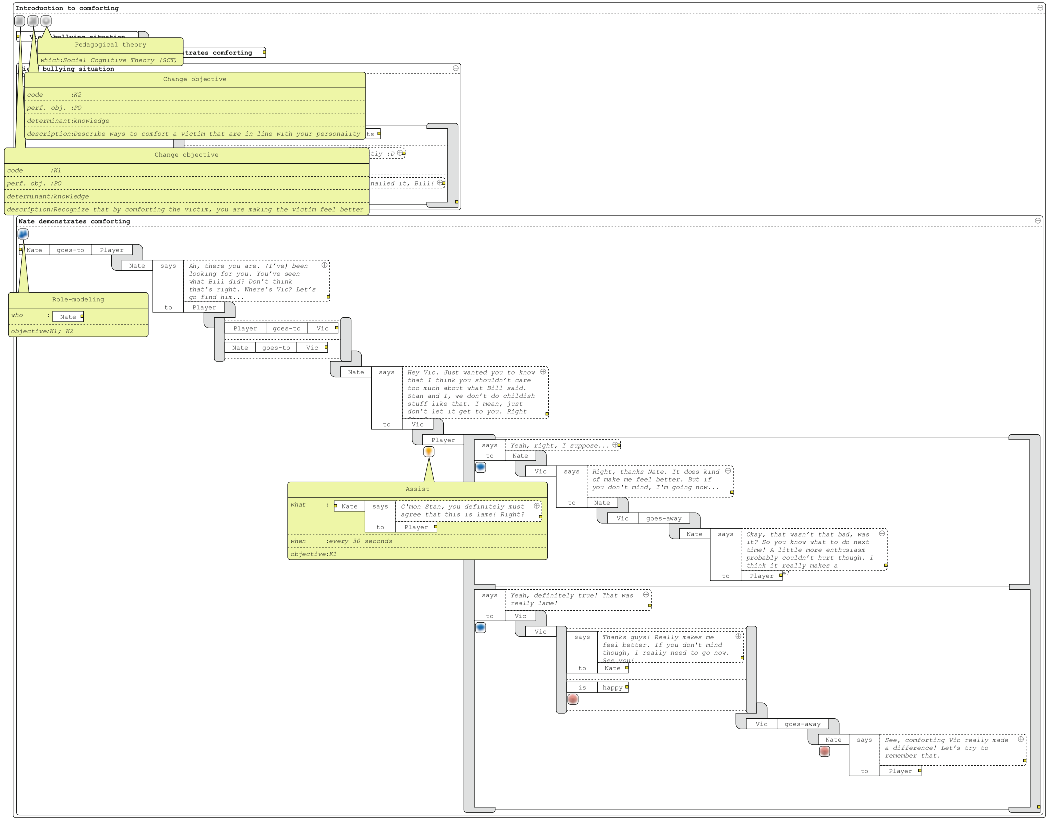


**Fig. 25.12** A scenario (Fig. 25.11) annotated with change objective PAs for determinant 'knowledge', a method PA for 'role-modeling' and a theory PA for SCT

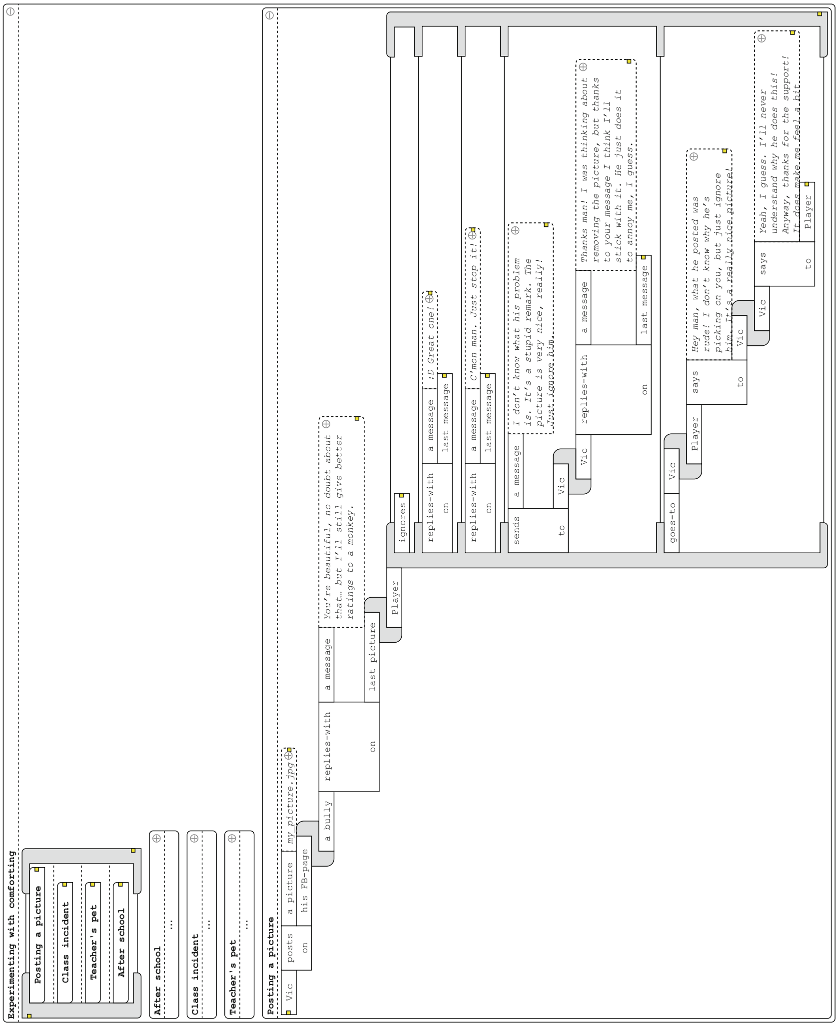


**Fig. 25.13** Example scenario 'Experimenting with comforting'

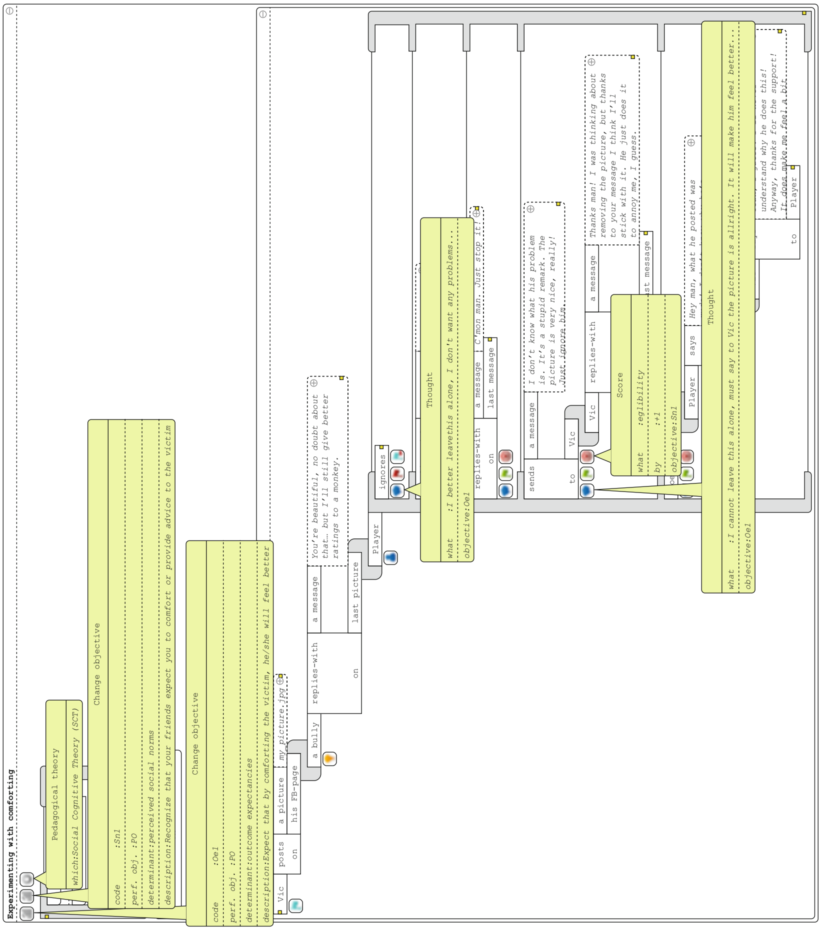


**Fig. 25.14** A scenario with change objective PAs for determinants 'outcome expectations' and 'perceived social norms' and action PAs for 'scoring', 'assistance', 'thought', and 'role-model'

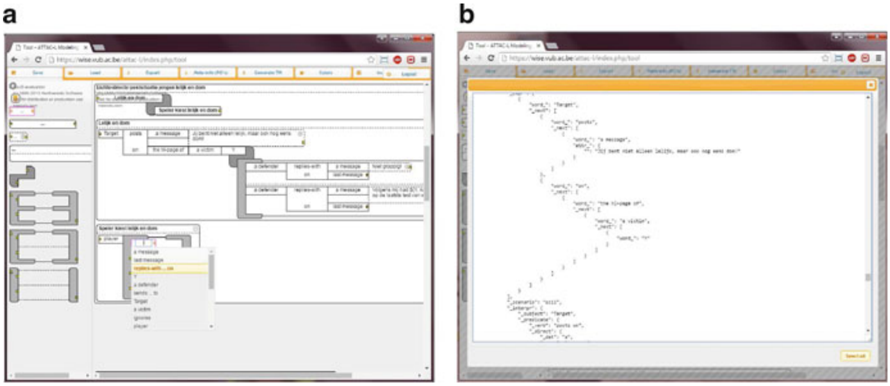

**Fig. 25.15** The ATTAC-L editor. (**a**) The editor pane. (**b**) Export to JSON

### *25.9.1 ATTAC-L Editor*

The *ATTAC-L editor* (see Fig. 25.15) allows modelers to specify a story model by means of a drag-and-drop functionality. Extra assistance is provided by means of automatic layout management and an auto-complete suggestion mechanism for the construction of game moves. Given the fact that the use of colors can help to increase the legibility of graphical models, the possibility for colorization of the graphical models is included as well. Note that a fixed color scheme for bricks is not imposed by the ATTAC-L language specification. Instead, the modelers can define their own color scheme or choose from a set of predefined ones.

The editor is implemented as a web-based tool, which inherently allows it to operate on a broad range of platforms while avoiding the requirement for installation on a local machine. Currently, the tool runs in major browsers like Google's Chrome, Mozilla's Firefox, Microsoft's Internet Explorer and derivatives. Modelers have the option to store and load their created models online to and from 'the cloud', or to export them from or import them to local storage facilities. The tool generates a JSON-based, machine interpretable data-structure representing the modeled story that serves as input for the tool's export module explained in the next section (see Fig. 25.15b).

### *25.9.2 Export Module*

The *export module* generates executable code or scripts from a story model for a specific targeted game environment. The basis for this translation is the interpretable JSON data-structure that is exported by the ATTAC-L editor.

As part of this module, an *Event Script Generator* (ESG) has been developed, which translates a (JSON encoded) model into Event Scripts. These scripts are files in XML-format and are specific for the target game environment. They contain a high-level description of the event driven specifications of the narrative. Currently, the scripts are specific for the game environment used for the ATTAC-L project. However, other game environments can be supported by developing new specific event script generators for these environments.

### *25.9.3 Simulator*

The *simulator* is a separate module that interprets an ATTAC-L model directly and executes the story in a simple and predefined 3D environment with predefined NPCs and behaviors. As such, the simulator provides a fast way to verify and test the modeled stories (Fig. 25.16a shows a screenshot from the simulation of the example from Fig. 25.17).

In light of the Friendly-ATTAC project, the current simulator targets stories related to cyber bulling. The stories can be executed in three different but predefined environments: a park, a house, and an office. Each environment has a number of predefined locations. For instance, the park has a playground, a fountain, a football field and a sitting area; whereas the house has different rooms. A couple of options are available to further customize the environment, e.g., day/night and weather conditions. There are also nine predefined NPCs, a fixed set of items and an inventory for the player. As the domain is cyber bulling, there is explicit support for social media such as an e-mail application interface, a Twitter interface, a Facebook-like interface, and a text-messaging interface for mobile phones (for examples, see Fig. 25.18). Those interfaces are shown as an overlay when a related action

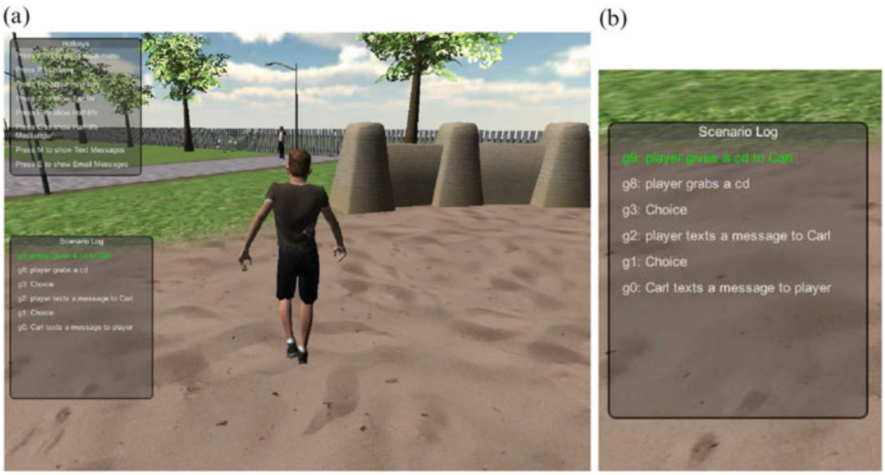


**Fig. 25.16** Simulating the scenario from Fig. 25.17. (**a**) The simulator in action. (**b**) Detail of the scenario log

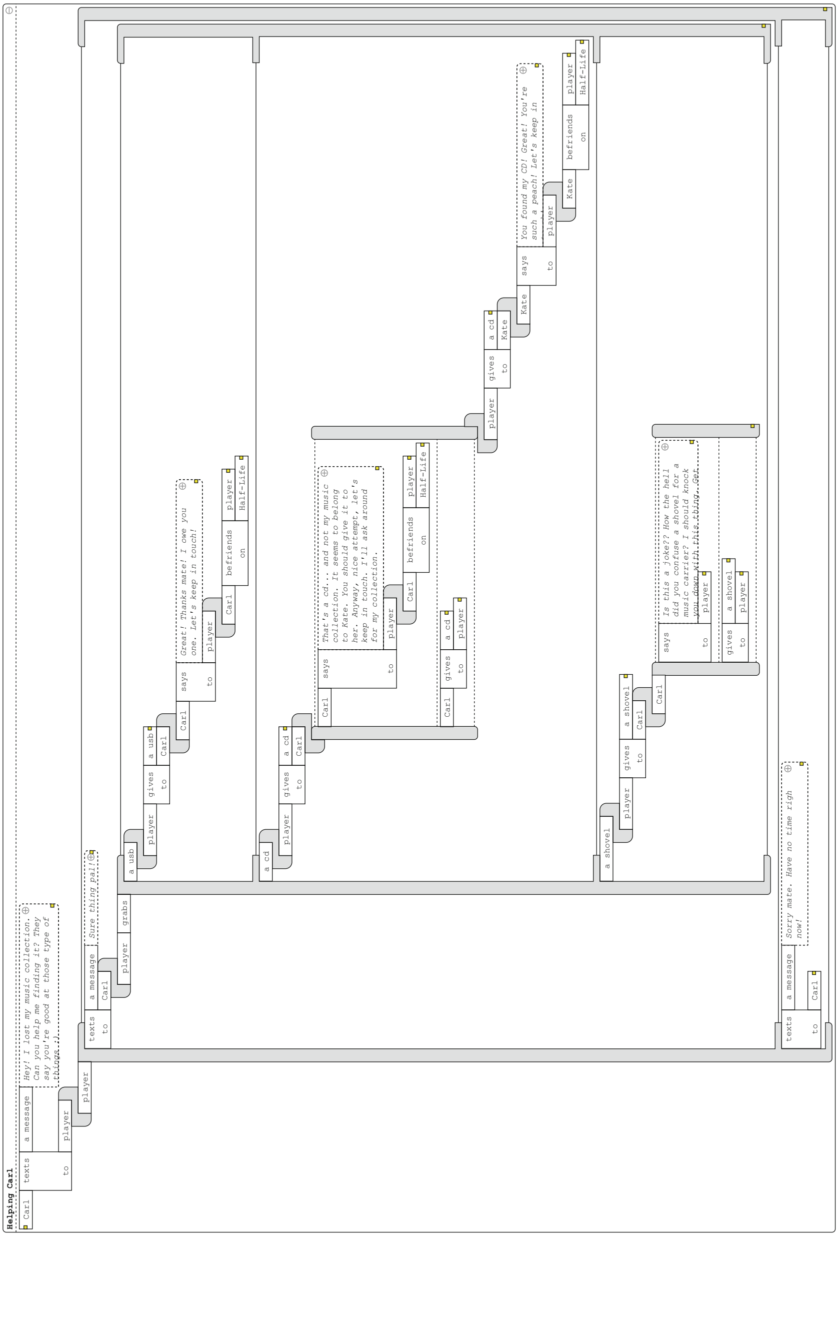


**Fig. 25.17** An example scenario 'Helping Carl', running in the simulator in Fig. 25.16a

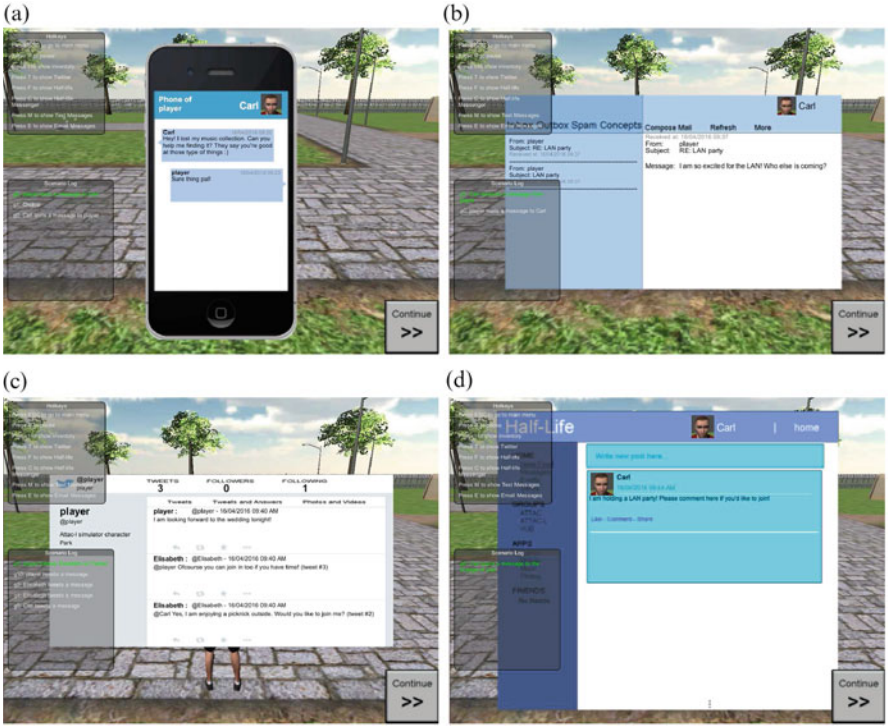


**Fig. 25.18** The social media interfaces. (**a**) Text-messaging. (**b**) E-mail. (**c**) Twitter. (**d**) Half-life, a Facebook-like social network

is performed in the story. However, the user can always inspect the social media interface using function keys.

To be able to execute the game moves defined with ATTAC-L, the verbs used in the game moves are associated with specific behaviors for the NPCs. Some general behaviors have been predefined for verbs, such as ‘walks-to’, ‘goes-to’, ‘says-to’, ‘gives-to’, ‘picks-up’, and ‘grabs’. In addition, behaviors have been defined for the common verbs used in cyber bullying, for example for ‘chats-to’, ‘tweets’, ‘re-tweets’, ‘follows-on’, ‘emails-to’, ‘posts-on’, ‘comments-on’, and ‘likes’. Conversations among NPCs and between NPCs and the player, which are specified in ATTAC-L with the verb ‘says-to’, are simulated using pop-up dialog boxes (see Fig. 25.19a). The NPC that is talking is shown at the left side of the dialog box.

The simulator keeps track of the steps followed and displays them in a scenario log (see Fig. 25.16b, a detail of the scenario log of Fig. 25.16a)). The last performed step is shown at the top of the list and is marked in green. When the player has to make a choice, the possible options are showed on the screen. Once the user of the simulator selects an option, the story will continue in accordance with that choice (see Fig. 25.19b). This allows to try out different paths in the simulated game.

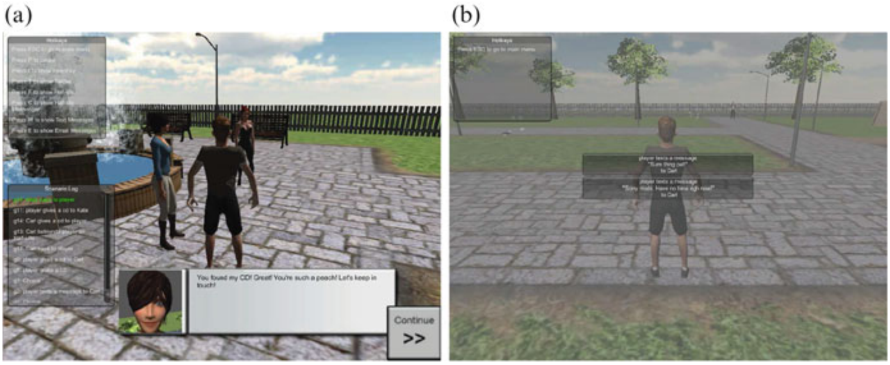


**Fig. 25.19** Interactions within the simulator. (**a**) Talking with an NPC. (**b**) The player is presented with a choice

The simulation can be done in two modes. In the ‘step-by-step’ mode, the simulator performs the game moves one by one. The mode requires the user of the simulator to explicitly instruct the Simulator to continue after each step. In the ‘continuous’ mode, the Simulator will stop only on occasions when the player needs to make a choice or when the user presses the ‘pause’ button.

The simulator takes the JSON data structure of a story model as input and is implemented using Unity.[1] Unity’s built-in path finding system (Nav Mesh)[2] is used to simulate the movement of the characters. JSONObject[3] is used for parsing the JSON data structure. All scripts are written in C#.

The current simulator is tailored towards the cyber bullying domain but by providing other predefined NPCs and behaviors, the simulator can be adapted for use in other domains (see also future work).

## 25.10 Evaluation

The DSML and its toolset were used in the interdisciplinary Friendly ATTAC project (Friendly ATTAC 2012) for developing a serious game against cyber-bullying. The team was composed of game developers, narrative designers, and people from computer, social and healthcare science. The team applied IMP (Bartholomew et al. 2011) to identify intervention methods that could be incorporated in the serious game. The social scientists in the team developed the story models using the ATTAC-L editor with some support by the developers of ATTAC-L. In total,

[1] https://unity3d.com/

[2] https://unity3d.com/learn/tutorials/modules/beginner/live-training-archive/navmeshes

[3] https://msdn.microsoft.com/en-us/library/system.json.jsonobject(v=vs.95).aspx

7 story models were developed consisting of 91 separate situations: 40 'neutral' situations, 26 minor and 25 severe bullying-situations. Using the pedagogical annotations of ATTAC-L, the selected pedagogical strategies were documented and the intervention methods were integrated into the story models. The story models were translated into game-engine specific event scripts by the Event Script Generator. Development of the game environment and scenes was also done in a model-based manner by means of a Sandbox Editor (Van Hoecke et al. 2016). The sandbox exports this environment model in the form of XML files.

In parallel with the social scientists, the game developers worked on the implementation. This included the translation of the domain vocabulary into implementation concepts, i.e., the domain actions and behaviors. For the cyber bullying domain, for instance, they implemented behaviors such as 'send-to' and 'post-on'. Furthermore, they created those parts of the game that would not be generated, like the user interface, levels and gameplay code. Finally, the developed code was used in combination with an interpreter to create a running game from the event scripts and the environment model (Janssens et al. 2014).

In addition to the use of ATTAC-L in the Friendly-ATTAC project, we also conducted a first small-scale evaluation to test whether our modeling language and toolset satisfies our objective. In other words, we investigated whether the language and the toolset suit the needs of people without programming knowledge and skills. Four people participated in the evaluation, each with a background in game narrative design but without formal schooling in programming. None of the participants had prior experience in modeling stories with a DSML.

The evaluation took place as follows. First, the participants received a small introduction on the purpose of ATTAC-L and how to use it. They also received an example story model and a written outline of the syntax rules. They were then asked to model a small, prescribed story provided in textual form. For this purpose, we used a scenario about a player who has to escape from a locked house and having three possible ways of doing so. The participants were then asked to sketch the story-flow on paper. Next, they were invited to model the story with the help of our modeling tool. The participants were provided with a comprehensive list of actions and entities (nouns, pronouns, verbs, adjectives). They could ask for assistance at any given time. After completing the exercise, the participants were prompted to reflect on their experience and the difficulties they encountered. The results of this evaluation were generally positive. The participants reported that they understood the example, as well as the modeling assignment and were fully able to model the scenario. Furthermore, the participants reported that they found the syntax rules very intuitive and natural and thus had no difficulties in complying with them. It is worth nothing that early during the exercise, some participants were inclined to model story-flows that were too complex (e.g., by introducing more game moves than actually needed) or to create highly specific solutions (e.g., using specific pronouns instead of the more general common nouns). When they were made aware of this, the participants quickly adapted their solution accordingly.

Together with our experiences in the Friendly ATTAC project, this small-scale evaluation provides an indication that our graphical CNL DSML will be able to meet its goal. People who used ATTAC-L agreed that the models specified in this language were easy to understand, even without a programming background. Furthermore, in both instances, we saw indications that people without a background in programming are able to actively model narratives and pedagogical interventions using ATTAC-L. As such, ATTAC-L enables narrative designers to specify their stories in a formal format that can be processed directly, and enables pedagogical designers to add the pedagogical interventions. This way of working has two main advantages. Firstly, it helps to save time that is otherwise spend on elaborating the narratives and pedagogical interventions on paper and transferring it to the technically staff of the development team. Secondly, it supports better communication practices as it helps to eliminate ambiguities and prevent misunderstandings.

## 25.11 Conclusions and Future Work

In this chapter, we have presented the domain-specific modeling language ATTAC-L developed to enable a multidisciplinary approach for the development of narrative-based serious games. It provides the necessary means to designers with and without a background in IT to model the narrative and pedagogical methods for the serious game in a clear and structured manner. A designer can be anybody involved in the design process: a subject-matter expert, a pedagogical expert, a storywriter, a game developer, even an end-user. An important characteristic that allows all of these designers to work with and communicate through ATTAC-L is the absence of programming concepts, as well as technical and implementation aspects. Furthermore, the associated tools are carefully designed to be intuitive and easy to use by people without a background in IT. The narrative is expressed using a strict form of natural language and organized in a schematic representation to provide the flow of the story. An unobtrusive, yet versatile annotation system is provided to integrate the pedagogical aspects and layer them on top of this story-flow.

We have also discussed how to explicitly link the narrative with the pedagogical intervention methods. This linking approach has two main advantages. First, it allows modelers to incorporate the designed pedagogical methods into the narrative in a rigorous way and without both becoming entangled and inseparable from one another. The clear separation between the narrative and pedagogical aspects of the serious game enables modelers to concentrate on particular aspects of the game in accordance with their own expertise, while maintaining an overview of the relationships to all others aspects of the game. As such, ATTAC-L stimulates and enhances multidisciplinary collaboration. Secondly, the annotations provide detailed documentation of the relationship between the story and the corresponding pedagogical principles allowing for verification of whether or not the serious game conforms to these principles.

We have shown that in the context of the Friendly-ATTAC project (Friendly-ATTAC, 2012) social and health scientist were able to actively contribute to the development of a serious game against cyber-bullying by creating narrative models. These models were then used to generate parts of the implementation of the serious game. This helped to speed up the development process and facilitated an iterative development approach. We can thus conclude that the work presented in this chapter represents an important step towards (1) allowing people with expertise in various domains other than computer programming or game development to become actively involved in the creation of serious games. Furthermore, the work also provides a means for (2) enhancing serious game development because it helps to reduce the development time of serious games and therefore also their costs. After all, time and money are two of the major barriers that hinder development of serious games and inhibit their widespread use.

In future work we aim to extend the current toolset to allow for the easy customization of the modeling language and the tools towards different serious game topics. We will do this by using an explicit and replaceable topic vocabulary. We also plan to extend the annotation system to allow for the specification of gameplay related aspects. In addition, we will provide a means for automatic code generation for these gameplay aspects. Finally, we plan to investigate how we can formally assess whether the serious game conforms to its intended pedagogical design.

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# Chapter 26
# Immersion and Narrative Design in Educational Games Across Cultures

**James Baker, Vanissa Wanick, Mashael Asiri, Gary Wills, and Ashok Ranchhod**

**Abstract** Games have great potential as teaching tools, in part due to their immersive, intrinsically motivating narratives which compel players to deeply engage with their worlds. However, little research has been done into how the culture of the player shapes the design and impact of the narrative, and therefore the design of an educational game so it can most effectively teach to particular cultures. To help resolve this issue, several theories of narratives, education, immersion and cultural issues in games were investigated, in order to find the core aspects and common aspects about what can make educational game narratives culturally relevant and immersive. The outcome of this investigation is the INDEC framework, which demonstrates how to structure an educational game's design to incorporate cultural issues, in order to identify how engaging a game would be to players across different cultures.

**Keywords** Immersion • Culture • Educational games • Narrative • Serious games

## 26.1 Introduction

Games have the power to engage different demographic groups, such as children, disabled people or an elderly audience. Games also offer ways to motivate people intrinsically, by using immersion to deeply involve the player in its world. Moreover, games could help to foster educational purposes, by enhancing cognitive skills. For example, action-based gameplay can be effective at enhancing learning for dyslexic children (Bavelier et al. 2013).

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A game's narrative has a strong impact upon its immersion, giving the player incentive to continue playing (Qin et al. 2009). However, it is necessary to understand how this would occur in different cultures. By doing so, the specific characteristics of a game can be designed in order to more effectively meet the user's requirements and abilities. Although this is the main feature of user-centred design, it is important to understand the game design principles that could enhance learning skills across cultures.

The understanding of games for educational purposes merges the concept of education and entertainment through at least three levels, such as presence, reinforcement and motivation. However, how would people from different backgrounds understand this message?

Learners from different cultures learn in different ways. For example, Chinese learners could be practical, deep thinkers or Confucian, based on their relationship and egalitarianism (Wachob 2000). In this scenario, until 1905, Confucian scholars hugely discouraged Western creativity. Moreover, in the Chinese culture, the concept of 'face' is important, especially because the relationship is crucial in education. In the case of Western society, the learning and educational approaches borrowed concepts from individualistic notions, progress and creativity. In other words, the educational experience is a process that combines culture and social interactions.

The objective of this study is to build a conceptual framework that could represent the application of game narratives in educational games for people from different cultural backgrounds. For that, we ask two questions:

- What is the relationship between culture, narrative and immersion in educational games?
- What are the best practices for the design of educational games across cultures?

## 26.2 Cross-cultural Games and Education

Culture has many definitions, but across all of them, it shapes people's responses and preferences to computer systems and communications. Hofstede (1980) defines culture as a system of patterns that differentiates people of one group from the other. In addition, Hall (1977) argues that culture cannot exist by itself, because it is a shared construct.

In games, the consideration of culture is very important. Concepts like cultural appropriation (Vasalou et al. 2014) could help to incorporate relevant meaning and representations inside the game without the risk of being stereotyped; the relationship between culture and games is therefore a natural development of design. Games can even be considered as cultural artefacts, through representation and transformation (Salen and Zimmerman 2004). In the representative level, games could be a reflection of a cultural context, including values and ideologies, whereas in the transformative level, games are interactive systems that provide different forms of participation to the player (Salen and Zimmerman 2004). This means there are two ways to understand games and culture: one from the perspective of the game and another from the perspective of the player. This in turn leads to the question: what are the elements that translate cultural meaning to the players inside the game?

The way that education is understood and contextualised has strong sociocultural variance (Kozulin 2001). This can be seen very clearly by examining the various educational curricula from around the world. For instance, whereas the UK supports a Piaget-inspired scaffolded approach to learning that is strongly structured and teacher-led, in New Zealand, the Te Whāriki system promotes freedom and minimal state and teacher involvement whilst promoting biculturalism (Duhn 2012). In China, the education system has an ethos of long hours and discipline (Kozulin 2001).

It is possible to understand why two countries can have such very major differences in the basic cultural conception of the social space. In China, this is typically traced back to the development of Confucianism (Fang 2014). A socio-philosophy of ethics, humanistic Confucianism was the dominant mode of thought that underpinned the development of China as a nation. This understanding conceptualises human relationships as being fundamentally sacred and helps to explain why China developed such a low individualism index (Fang 2014). This way of understanding the social space then underpinned political systems is the case of China, which is a blend of communist and socialist ideologies (Kleinman and Lin 2013).

When these ideals are reinforced through the government, they are imprinted within all spears and systems of society – including within schools – and thus the cultural tendencies are self-perpetuating (Burr 2015). There is a formal theory that explains this process, known as social constructivism. This theory explains how social and cultural norms develop within society, often to such a degree that they are entirely invisible to those around them (Burr 2015). Just as British school children may find the authoritative nature of Chinese education systems intimidating and oppressive, Chinese school children would struggle if they were placed directly into the value-based Te Whāriki system with few rules, limited authority and high levels of personal independence or into a British system (Wu et al. 2014). This is because each child would be out of his or her ‘normal’. Therefore, understanding different sociocultural norms – and particularly their variances – is highly relevant within the context of the development of cross-cultural educational games. Only by fully understanding culture can designers create meaning for the players.

A learning activity is dependent on the context and on the way members from a culture see the world (Brown et al. 1989), which means that learning cannot be separated from culture. This could be represented by the process of ‘enculturation’ or the incorporation of beliefs and values from a social group (Brown et al. 1989, p.7). Moreover, culture can influence the way students behave; this aspect can be implicit or explicit (Brown et al. 1989). Thus, although cultural influence may not be evident, it should be taken into account. Brown et al. (1989) also advocate that observation and actions in real contexts could help to improve learning, particularly through imitation.

The game narrative is one of the ways to understand this relationship, especially in games for education, as it provides context and meaning to the player's actions (Qin et al. 2009). Another way to illustrate this aspect could be through interface design, with respect to a game's world.

The interaction between the player and their in-game character (or 'avatar') is essential to represent the characteristics of the game world and interactivity (Burn and Schott 2004). But how is this narrative represented by a combination of animation, visual assets, music, textual information and sound effects? The question could be opened to a wider understanding of different audiences and a narrative fit to their preferences. It is possible that there are differences across cultures in the way they understand the game narrative and engage with it. According to Burn and Schott (2004), this could be achieved with the avatar design, through popular tales and hero-style stories. This aspect puts the concept of game world design and aesthetics as important actors in game narrative design and representation. Furthermore, the game world design can be considered as part of the interface design. The approach of interface design as narrative is supported by Bizzocchi et al. (2011) as a combination of game aesthetics, metaphors, gameplay decisions and different points of view in the game. However, how would those metaphors vary across cultures? How should designers build an effective cross-cultural interface design? This situates the interface design as an important element to be considered in educational games across cultures, particularly from the narrative perspective.

## 26.3 Narrative Cohesion

Hargood et al. (2011) argue that there are at least five narrative cohesion variables, including the logical connection of the content and narrative, the themes, the genre, the narrator and the discourse styles. This five-variable framework could help to analyse separated parts of the game narrative. Although the approach is valuable, there is further investigation needed about how it can be applied to game narratives, since they have key differences from other storytelling media (Juul 2001); additionally, storytelling methods could be impacted by variations in devices and different users. Maybe different game genres are more suitable for different cultural backgrounds and specific subjects? What about maths or foreign languages?

Creating narrative cohesion from a standpoint of complete innovation has always been more of a challenge across the gaming industry as a whole, and within educational software in particular (Bizzocchi et al. 2011). Formal attempts have frequently failed to engage learners unless tethered to narratives that children already know and understand. Time, context and memory are also three important elements when considering narratives. For example, experiences depend on time, context and memory, which is often episodic (Hazel 2008). Thus, temporality could be also something to be explored in terms of narrative cohesion.

The narrative of a game is used to give fundamental meaning to the actions the player undertakes within the game (Qin et al. 2009); without a narrative, there is no point to the game's world and characters. The indication is that game narratives differ from narratives of other storytelling mediums because of the involvement of the player. Consequently, while more traditional narrative techniques are important for constructing engaging stories in games, they also require additional considerations for how the player interacts with the game and its world.

The two narrative structures commonly associated with games in academia emphasise this theme of interaction. These structures are known as embedded and emergent narratives (Aylett 1999; Jenkins 2004; Salen and Zimmerman 2004, pp. 383–384). In embedded narratives, the core narrative goals are predetermined and do not change in each playthrough; while each player may use different methods to achieve these goals, the progression of the game's story is ultimately the same. By contrast, in emergent narratives, the story progression is dependent on the player's interactions in the game, providing unique narrative experiences for each player.

As far as immersion is concerned, embedded and emergent narratives have differing positives and negatives. The more rigid structure of embedded narratives allows more control over story elements, making it easier to generate memorable and engaging moments, specific to the game's characters and world. However, this rigidity can potentially weaken the game on repeat playthroughs, since the player would already be familiar with the story, meaning its impact is lessened. Emergent narratives, on the other hand, can overcome this problem; a narrative shaped by player interactions makes it almost certain that new possibilities will present themselves to players on subsequent playthroughs. With that said, there is the danger with this approach that the emerging narrative could be dull, or even not develop at all (Aylett 1999).

However, there are suggestions as to what aspects affect how engaging narratives with emergent properties are; in their investigation of game narratives, Qin et al. (2009) concluded that there are six factors which can contribute to a player's immersion in the narrative. The first of these, the two factors precede immersion: 'curiosity' and the game's 'difficulty'. After the player becomes immersed, the factors responsible for keeping the player immersed are 'concentration' on the story, how much 'control' the player has over the game world and towards their solutions of gameplay challenges and their 'familiarity' with the story, including their knowledge of the story and how well they can predict what will happen next. Lastly, when the player has left their immersed state, their engagement in the narrative can be judged by their 'empathy' for the game's characters. These factors would suggest that engaging game narratives are primarily emergent, since most of the immersive qualities they describe all depend on the player's actions and sense of discovery; the exceptions, 'concentration' and 'empathy', imply that engaging game narratives require a game world that the player cares strongly about.

One way of facilitating this empathy is through the player's in-game avatar. Research by Belk (2014) shows that gamers can come to identify strongly with their avatar, in what can be described as a blending of the game world and reality, creating a new form of sociology. Avatars can even become alter egos for the player (a phenomenon which Squire calls a 'projective identity' (Squire 2006)) and in their minds can embrace a life of their own. The role of the avatar in engaging players further emphasises the importance of player involvement and choice in forming engaging game narratives.

With this in mind, it is important to note that cultural differences can impact how receptive players are to these avatars. Koda et al. (2009) carried out research into how avatar design varies across cultures and found that whilst there are variances between east and west in terms of avatar preference, there are also some universals. For instance, positive facial expressions were preferred by the majority of users in both cultures. However, they also found that gestures could be highly misleading, countering the effects of facial expressions. This is unsurprising, because body language is known to cause widespread problems within intra-cultural communication. What is polite in one culture may be seen as being dismissive in another. What is friendly in one may be interpreted as being over-friendly in another. Such considerations are important in order to prevent problems when appealing to different cultures. This aspect could be also applied into non-playing characters (NPCs). In fact, NPCs could function as a way to provide adaptive experiences in educational environments (Peirce et al. 2008).

Whilst different in how they approach player interaction, the 'embedded' and 'emergent' structures are not incompatible for a game narrative. Indeed, Salen and Zimmerman (2004, pp 385–399) argue most game narratives combine the best elements of both, joining the overarching goals, setting and characters of embedded narratives with the choice of world interaction offered by emergent narratives.

To this end, Salen and Zimmerman also proposed a set of elements that make a game narrative engaging. The first element comprises of the overarching 'goals', built around gameplay and story, which the player must accomplish in order to progress. These goals are augmented by impeding 'conflict' that the player must overcome, and some 'uncertainty' about how the narrative will progress (ensuring it is not completely predictable). The game's 'core mechanics' further affect how the game's narrative and message is conveyed, particularly combined with an environment ('narrative space') that presents interesting problems which encourage world-based experimentation to solve, and demonstrates 'meaningful consequences' to the player's in-game actions. This environment is further supported by 'narrative descriptors', which are representations that convey the game's story.

These elements indicate three recurring themes regarding engaging narratives, similar to those uncovered by Qin et al.; the first is a game world that feels real and responsive; the second is allowing players to interact with such a world, so that they feel like a part of it; and the third is the integration of game mechanics into the narrative. The implication, in short, is an engaging narrative should be woven into the gameplay and interactions the player experiences, to create a world that they implicitly want to spend time in.

Part of creating such a world is in providing reasons for exploration. One notable aspect of this is narrative 'plausibility'. In Dickey's study on narratives in educational games (2011), she qualifies 'plausibility' as a consistent and believable context of the narrative, created through the interplay between the characters, game events and environment; through this context, the player can understand what is possible to do in the world, and from that how to approach particular challenges within it. A part of constructing plausibility can come in the form of world details; in the context of the acclaimed story-based role-playing game *Final Fantasy VII*, Burn and Schott (2004) emphasise the idea of exploration and using branching details (inessential to the main story) as a way of increasing a player's agency within a game world.

One approach that is frequently used in educational software is to simply abandon narrative cohesion and design the game as a form of interactive textbook (Kirchgessner and Ketelhut 2012). According to Kirchgessner and Ketelhut, (2012), teachers are frequently more comfortable with this approach, and parents also have higher levels of trust. For instance, a company has created a reading software under the name 'Lexia', and it uses the same narrative approach as textbooks by having multiple small game-based exercises (Lexia 2016). What it claims to offer differently is personalised learning, so that the software understands the user's progress and modifies their daily tasks in response to their personal needs. This person-centred approach to educational gaming is reflective of the primary focus of the formal industry to date and is found in informal sectors such as app development (Kickmeier-Rust et al. 2012). Indeed, McCusker et al. (2013) see adaptive educational systems and content personalisation as being crucial to the future of this branch of the industry.

However, as De Mul (2015) explains, when people play games they inevitably form narratives and ludic identity formation. There are high levels of interactivity, and this is due to the fact that the human self is not a self-contained object but is in constant dialogue with the world around it – both informing that world and being informed by it. In order to interact with the world, De Mul (2015) explains that there must be high levels of referentiality, communicability and self-understanding in order for the individual to mediate with the world. This means that the integration of these elements within a computer game would affect the learner's engagement.

Padilla-Zea et al. (2014) argue that for narrative cohesion in educational games, there must be a clear balance between ludic elements and educative content. They note that central to this is the composition of the story, and this must be targeted specifically to the needs of the cultural group. Padilla-Zea et al. (2014) advocate utilising a model-based approach whenever attempting to construct a suitable game narrative. Interestingly, however, Padilla-Zea et al. (2014) do not include discussion on identity construction in educational gaming, something that many other authors see as being crucial.

### *26.3.1 Narrative and Education*

Interactive stories were some of the earliest types of educational software to emerge and led the way in the development of educational gaming (Zemliansky 2010). These narratives were, however, typically tied to existing media. For instance, in 1983 several educational titles were released on the Atari 1600, but all of these were under the well-established Sesame Street brand and used familiar characters and game narratives from the show.

Furthermore, narrative and education could be studied through the lenses of digital storytelling. By definition, digital storytelling involves different multimedia tools, including interactive media, particularly through a participative approach (Robin 2008). This strategy allows students and teachers to engage with the learning content. In the educational context, seven dimensions compose digital storytelling, which include: the point of view, related to the purpose of the story; the dramatic question, as a way to grab the audience's attention; the emotional content; personalisation; soundtrack; economy, as a way to give enough content to the audience; and finally pacing (Robin 2008). The combination of those elements should provide more engagement for students, and hence it is possible that these dimensions could be explored in serious games. However, the big challenge is to integrate the educational content with each dimension.

One way to analyse this is through personal narratives, informative stories and stories related to a historical event (Robin 2008). Informative stories and historical-related narratives are usually used by teachers in the educational environment; personal narratives can have historical events in the background, in order to illustrate the educational content (Robin 2008). This means that those narratives could be employed in first or third persons. For example, in Brazil, the serious game *Buzios: ecos da liberdade (Buzios: echos of freedom)* was created in order to teach students about particular issues of Brazilian history. However, one of the problems highlighted by Souza et al. (2010) was that the students were not interested in the textual information provided by the game. This could be related to at least two aspects: the lack of integration of educational content with the game, forcing the students to have 'pre-defined' attitudes before playing the game (e.g. feeling bored) or the need to change the game narrative in order to fit the students' expectations.

Another way of integrating educational content into game narratives was investigated by Dickey (2006), who created a framework of design heuristics concerning the issues of how to structure such a narrative. Firstly, the initial challenge should be presented, to act as an initial 'catalyst' to start the story. Following this, smaller obstacles/challenges should be placed leading up to this initial challenge, to help impart the skills and knowledge the learners will need. The roles of each character the learner encounters should also be established (e.g. a mentor providing guidance, a guardian that tests the learner's knowledge). Additionally, the setting needs to be established, including the physical space the learner occupies, the progression of game time, the in-game environment and tone and the emotional and ethical facets of the game's characters. Finally, a backstory is recommended to establish the setting, and cut scenes to advance the story, provide feedback and introduce new challenges. While only providing an overview of the potential issues, the framework does emphasise the importance creating a world and challenges which reinforce the game's learning content, and of compelling the player to proceed with a story and a role they actively feel engaged with.

Furthermore, in terms of education, narratives can function as a way to provide conversations within a context, particularly in constructivist learning theories (Hazel

2008). This suggests that narratives could enhance learning by coherent experiences. In this scenario, ways to provide context through narratives are agency (i.e. people involved in the narrative); typification (i.e. adoption of conventional meanings); situated significance, conveyed by social factors; and coherence, related to problem solving (Hazel 2008). Thus, it is possible that conventional meanings could be attached to social norms and cultural rules. The challenge, however, is to explore the narrative dimensions that convey cultural significance.

### *26.3.2 Narrative and Culture*

Game narratives provide context and meaning to the player's actions (Qin et al. 2009). Context is a crucial part of the system's meanings. For example, the red colour for the traffic light does not mean 'stop', but 'motorists, stop' – which reflects the relationship between context and function (Hodge and Kress 1988). In addition, narrative could be strongly attached to logical order of problems. For example, language learning could follow different patterns: English speakers are more direct, whereas members from Oriental cultures communicate in 'circles' (Kaplan 1966). Thus, this aspect could influence the way the narrative is presented to players in different cultures, particularly in different contexts.

Another important point to understand is the role of language in narratives. In different cultures, language provides ways to enhance cultural connection and belongingness through cultural expressions and contexts (Kramsch 1998). In other words, language is a group of signs that makes sense for a group of people. This means that the representations of a text, voice or any format of language should be culturally situated. Thus, choices of words and meanings should be carefully presented in a game narrative. Language can be also influenced by social conventions. For example, polite expressions and appropriateness of language utilisation can be conveyed by culture (Kramsch 1998). This suggests that in a game, the narrative should be in accordance to those norms and conventions in order to provide a correct and appropriate meaning to the player. Thus, this aspect could also influence both states of game narrative: emergent and embedded. For example, the way the goals are presented in the game and the story behind a character could replicate meanings and popular words that would only make sense to a particular group of people.

Another way to understand the integration of narrative and culture is through self-identity. People tend to build their own stories around the rules and norms of a particular culture, in order to maintain a coherent narrative (English et al. 2008). This suggests that culture regulates personal narratives. This is consistent with De Mul's (2015) idea that the individual is influenced by the context and the context is influenced by the individual's choices and reflections upon those choices. Thus, in a game, this could be attached to both narrative states (embedded and emergent), influencing the level of immersion provided by gaming and educational experiences. This relationship is illustrated in Table 26.1.

**Table 26.1** The relationship between narrative, immersion, education and culture

| | General principles | Education | Culture |
|---|---|---|---|
| Narrative | Embedded narrative, emergent narrative | Participation, purpose, attention, emotion, personalisation, sound, content balance, pacing | Context, meaning, logical order of problems |
| Immersion | Challenge, fantasy, curiosity, feedback | Experimentation, reflection | External/social motivators, cultural significance |
| Narrative and immersion | Goals, conflict, concentration, control, familiarity, curiosity, difficulty, empathy, core mechanics, narrative space, narrative descriptors, plausibility | Experimentation: curiosity, difficulty, core mechanics, narrative space, narrative descriptors, goals | Familiarity, narrative descriptors, narrative space, conflict, plausibility, goals |
| | | Reflection: concentration, control, conflict, plausibility, familiarity | This could be supported by: relevant meaning, representations, language, game elements (e.g. avatar design, NPCs), game content, participation |
| | | | This could provide: practical, deep thinking, Confucian, progress, creativity, real context, imitation |

## 26.4 Immersion

A vital aspect of all games is the idea of immersion; the core goal of a game is to provide a positive experience that can engross the player's attention for long periods, which compels them to reflect on that experience and wish to return to it. Not only is this immersiveness valuable for the longevity of a game, it also convinces the players to pay attention to – and care about – the messages within the game, which makes them useful from an educational standpoint.

One idea that provides the foundation of immersiveness is that of 'flow'. Csikszentmihalyi (1990) describes flow as being a state of 'optimal experience', where a person's attention is singularly focused on an activity, which is enjoyable and meaningful to them. In this state, the person is intrinsically motivated to continue from their own enjoyment and a desire to continually improve at the activity.

When considering what makes ‘enjoyable user interfaces’, Malone (1982) developed three categories of heuristics: challenge, fantasy and curiosity. The heuristics for challenge focus on presenting clear goals, feedback regarding how close the user is to achieving them and a general level of uncertainty about whether the will reach the goal, such as through escalating difficulty. The heuristics for fantasy involve integrating ‘fantasies’ (evocations of objects/situations that are not really there) that have emotional significance to the player and representing the mechanics of activities through ‘metaphors’ which the player is familiar with. Finally, the heuristics for curiosity involve providing an ‘optimal’ level of information in the interface (using audio/visual elements, carefully placed randomness and humour) and stimulating the user’s desire for having as complete knowledge as possible (e.g. in order to solve particular problems).

With games specifically, Brown and Cairns (2004) suggested that immersion has three levels of increasing intensity. The first level, engagement, occurs when the players first start to get involved in the game, through intuitive and sensible controls, gameplay preferences and an investment of effort. The second, engrossment, occurs when the player becomes emotionally affected by the game. Finally, total immersion happens when the player devotes exclusive attention to the game; however, this level is only experienced briefly, as opposed to flow, which lasts for the duration of the person engaging in an activity.

For educational games, creating an immersive experience seems to involve active engagement with the subject matter to solve particular problems. Kiili’s experiential gaming model (2005) suggests that, in educational games, students engage in a cyclical process of formulating ideas and experimenting with them in order to overcome particular challenges; the idea is that with successive testing and reflecting, the player gains a deeper understanding of the game’s mechanics and by doing so enters the immersive ‘flow’ state.

Barab et al.’s transformational play theory (2010) supports this experimentation theme. Designed for the development of educational games, the theory emphasises the importance of the player knowing academic concepts to progress, advancing the story according to the player’s choices and showing the consequences of these decisions.

Having an environment to experiment in additionally helps immersion in terms of an engaging fantasy context. In their investigation into the features of instructional games, Garris et al. (2002) expand upon Malone’s idea of ‘fantasy’; they suggest representing real-world processes through metaphor helps to focus the player’s attention, thus better facilitating immersion. Additionally, a core appeal of fantasies to players is being able to partake in situations and roles that they would not normally experience, with their actions having no real-world consequences. Furthermore, it is argued that having the fantasy contexts related to the game’s subject matter (‘endogenous’ fantasies) is more effective as a teaching tool than fantasy contexts that are unrelated (‘exogenous’ fantasies). Thus, if the related fantasy interests the player, they will become more interested in the subject matter. The implication of these points is that one core immersive quality of educational games is a 'safe space' for the player, which is supported by an interesting narrative context relating to what the game is trying to teach.

People from different backgrounds tend to follow experiences that situate them into their social contexts (Salisbury and Tomlinson 2014). Research in flow and immersion often reflects the individual experience, overlooking possible influences of external factors. This means that the participation of external and social motivators could influence the way people feel immersed in a game. This could be translated by an 'appropriate' immersive state, in which it is acceptable to play a game and have fun with it, without affecting the others in the group. Salisbury and Tomlinson (2014) argue that this aspect is related to a cultural significance. In an educational context, this could be extremely important, particularly if all the students and the teacher are involved in the same game. Moreover, this could have a reflection in the norms inside the game.

Qin et al. (2009) presented six dimensions to measure immersion of the player in the context of game narrative, composed of curiosity, flow, understanding, control, challenge and empathy. The highest point of the analysis is the interactive characteristic of the game: games are interactive systems. Moreover, players are more than just the audience, but also narrators, which changes the role of the user to a more active one. However, the sample of their study was composed by Chinese students, from 19 to 25 years old; are there any differences for people from other cultural backgrounds?

The role of interactivity and exploration would be important to consider in terms of world design as well. For instance, is there any cultural inclination to explore environments in particular ways? Would immersion be easier to achieve if the characters' ways of communicating were familiar to the player, or would novelty be more appealing?

## 26.5 The Framework for Immersion and Narrative Design in Educational Games Across Cultures (INDEC)

Considering those principles, we introduce the framework for immersion and narrative design in educational games across cultures (INDEC) (see Fig. 26.1). The framework incorporates different aspects of game design principles, narrative design and immersion in a cultural setting. The purpose of this framework is to build cultural awareness and significance by the understanding and manipulation of elements that involve narrative design and game design dimensions.

The INDEC framework is composed of: (1) educational goals (EG), (2) game design (GD), (3) narrative, (4) experimentation, (5) reflection, (6) cultural relevance (CR) and (7) immersion.

Each element of the framework is followed by a cultural awareness that defines EG. Learning outcomes and educational goals (EG) depend on the cultural setting; for example, EG could be structured to be more practical or creative, depending on

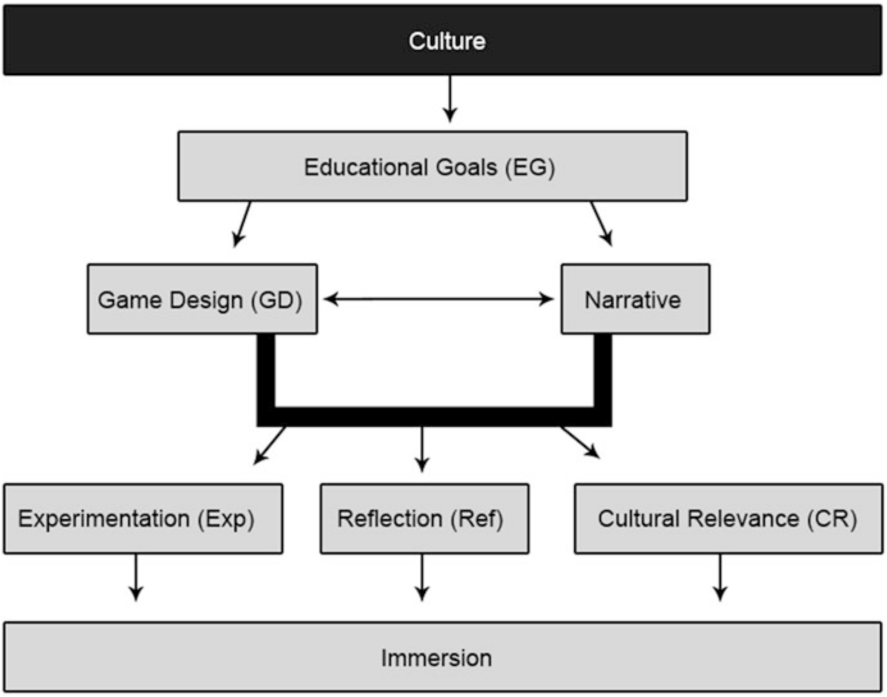


**Fig. 26.1** Framework for immersion and narrative design in educational games across cultures (INDEC)

the students' cultural background. Thus, as the EG are built on students' skills and educational curriculum, the understanding of those goals a priori is crucial for the design of an educational game. As mentioned previously, social interactions and the process of enculturation influence the educational experience.

Game design (GD) is the design of the game itself; it includes dimensions of user interface design and the game world, combined with the game narrative. In different cultures, it is important that the game has a significant meaning, expressed by game representations, game content and language. In an educational game, the game content should be tailored not only according to the EG, but also in accordance to cultural relevance. Elements such as the game world, in-game avatar, NPCs, animation, visual assets, music and sound should be taken into account; the manipulation of those components could influence the way the players understand the game narrative. This could be also represented by game metaphors, popular tales and hero-style stories, supporting the game narrative.

As illustrated by Fig. 26.1, GD and narrative work together; this is expressed by the support of game design elements for the narrative. As mentioned previously, narrative in games can be classified as emergent and embedded. Although those concepts could overlap, in narratives across cultures, both concepts could be culturally dependent. For example, emergent narratives could depend on social factors and motivators, involving other members of a group or community; embedded narratives could be designed according to the cultural setting and EG. The important aspect to consider is that whether emergent or embedded, the game narrative is culturally situated. For example, in cultures that value creativity, the emergent narrative could be more relevant for the student and the goals of the game could be loosened. Moreover, there is a strong relationship between well-designed narratives and immersion; narrative elements such as goals, conflict, concentration, control, familiarity, curiosity, difficulty, empathy, game mechanics, narrative space, narrative descriptors and plausibility are a few aspects that contribute to immersion in a game. However, in terms of education, those aspects could be manipulated differently.

Experimentation (Exp) and reflection (Ref) are two important aspects that support immersion in educational games. Therefore, it is possible that curiosity, difficulty, mechanics, narrative space, narrative descriptors and goals could provide more Exp. On the other hand, concentration, control, conflict, plausibility and familiarity could improve Ref in an educational game, which suggests that each game narrative aspect could evoke different EG. However, how would this occur in a different cultural setting? Immersion across cultures is strongly related to cultural relevance (CR), and external and social motivators are the main elements that influence CR. This means that immersive experiences should be situated into a context.

The INDEC framework shows the integration of cultural awareness, EG, GD and narrative. However, in terms of immersion, a few aspects should be considered. For example, familiarity, the narrative space, narrative descriptors, conflict, plausibility and the presentation of the goals in the game could be situated according to a particular culture. These could be supported by relevant meaning, representations, language, game elements, game content and cues to participation inside the game. For instance, visual assets of the game could represent aspects that are familiar to members from a particular culture. In turn, the sounds and the music could evoke a sense of familiarity, thus promoting immersive experiences. Thus, the integration of GD principles is crucial for the delivery of immersive experiences for players.

The INDEC framework could be a way to understand and explore immersion in educational games across cultures. As explained in this section, culturally situated educational goals (EG) could guide game design (GD) principles and aspects of the narrative. Thus, if a culture prioritises creative thinking instead of practical skills, GD principles and narrative could give a sense of exploration to the players, allowing them to interact with game objects in different ways and exercise their creativity inside and outside the game. This could occur through experimentation and reflection, which are also supported by a cultural relevance of the overall game content. In other words, the INDEC framework shows two ways to investigate and study immersion in educational games across cultures: as a design guideline (represented by a top-down flow from culture to immersion) and as a way to measure effectiveness of educational games across cultures (as a bottom-top flow from immersion to culture).

## 26.6 Conclusions and Implications

In this chapter, the theories of cross-cultural game design in the context of educational games were explored through the lenses of game design narrative and immersion. From this exploration, we introduced the INDEC framework, with the aim to integrate several aspects of narrative design and immersion in educational contexts across cultures. The framework could be employed in different situations as a way to provide more relevance for players/students. For example, in cultures that value creativity, the educational game could be designed favouring curiosity and control, and the game design dimensions could support those principles. In terms of culture and immersion, the same game design elements could support a more experiential and/or reflective outcomes. Familiarity, the design of narrative descriptors and narrative space, conflict, plausibility and the presentation of the game goals could be the main elements supported by the game narrative and the game design in order to provide cultural relevance.

The INDEC framework could be employed before and after game design. In terms of game design guidelines, the INDEC could facilitate the design of educational games across cultures through the analysis of how well each design element is supported by the game narrative and game design. Moreover, during post-design, the INDEC framework could help to analyse existing educational games in order to improve their support for immersive experiences.

In the future, we expect to test the framework with different educational games across cultures through game analysis and interviews with students.

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# Part X
# Review and Methodology

# Chapter 27
# "I Just Don't Know Where to Begin": Designing to Facilitate the Educational Use of Commercial, Off-the-Shelf Video Games

**Kyrie Eleison H. Caldwell, Scot Osterweil, Carole Urbano, Philip Tan, and Richard Eberhardt**

**Abstract** This chapter documents the process and preliminary results of a two year project in which a team of MIT researchers, in close collaboration with local educators, designed and tested supplemental teaching resources for supporting educators in implementing the use of commercial, off-the-shelf games in their secondary level, humanities (e.g. social studies, history, languages) classrooms. The chapter also provides an overview of similar research in the field of game-based learning and addresses challenges likely to be encountered in such implementation processes, particularly in the American public educational context.

**Keywords** Commercial off-the-shelf games • Co-design • Curriculum design • Humanities education • Secondary education • Research documentation

## 27.1 Introduction

"I am not a gamer" are often the first words spoken by the teachers we approach for using games in their classrooms. "But my kids are!" Continued conversation often reveals a teacher's passion for puzzles, board games, and other playful digital and non-digital experiences the teacher was not categorizing as games. Confessing a desire to use games as part of a larger set of instructional strategies is likely followed by yet another disclosure: "I just don't know where to begin."

In the fall of 2013, the Massachusetts Institute of Technology's Education Arcade research laboratory submitted a proposal to a private research-funding entity, the Arthur Vining Davis Foundation, requesting support to explore the use of commercial, off-the-shelf (COTS) digital games (also appearing here as video games) in upper secondary, humanities classrooms. At the time, there was a significant amount of research being conducted around the use of learning games in

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STEM (science, technology, engineering, and math)-based classrooms and informal learning environments at all levels – primary (known in the American system, the designations of which we will use throughout this chapter, as elementary), lower-secondary (middle), and upper secondary (high) school. Yet, two key components were missing from the equation – the use of commercially popular games (versus games specifically designed as educational) and a focus on the humanities. We sought to tap the potential of commercially successful digital games for learning. In particular, we planned to facilitate widespread, effective use of commercial games to support learning in high school literature, history, and civics classes and contribute to research that explores how learning occurs through gameplay and identifies the best classroom practices for achieving desired learning outcomes. We proposed to conduct the work in five phases:

- Researching and assessing best practices among high school humanities teachers who are already integrating popular commercial games into lesson plans
- Developing multimedia professional development resources informed by best practices, including model curricula that integrate select commercial games and are linked to national educational standards
- Piloting and assessing the first iteration of the professional development and curriculum materials with classroom teachers during the second year of the project
- Revising materials based on pilot outcomes
- Disseminating the materials nationwide via relevant professional conferences relevant print and digital media outlets

Due to ongoing local and national policy conversations regarding the Common Core State Standards, which aims to maintain a national (rather than at the individual state level) set of criteria for and model of public education learning outcomes around the need for a greater emphasis on deeper, critical skill learning, we decided to focus our research and development efforts on developing activities and professional development resources that would support these emerging standards. Drawing on research in the field and our own experience as game researchers and designers and developers of effective games for learning, we hoped to identify and select popular games that might:

- Scaffold complex systems, allowing learning to build understanding incrementally through trial and error
- Include opportunities for collaborative learning and team play
- Model hypothesis testing and model-based reasoning
- Embed learning in a compelling narrative that engages students and motivates them to persist in the game when faced with challenging obstacles
- Provide multiple paths for problem solving to accommodate multiple learning styles
- Provide ongoing feedback and rewards that allow student to continuously monitor their own progress and motivate them to keep trying despite initial failures

In this chapter, we discuss how prior research affects our current work via a brief literature review of the use of COTS games in classrooms, with emphasis on secondary and/or humanities education, as well as other approaches to scaffolding teachers' use of specialized curricula around games and other media. Beyond this literature review, this chapter serves primarily as a full documentation of our project, from our research site's curricular context and other constraints and our specific methods to the ways in which our research goals changed over the course of the project's 2 years. Although this documentation is deeply situated in the specificities of our project, we present it as a methodological frame, with reflections upon such a methodology and the issues that arise within and around it, so that this documentation may be of use to other researchers and educators who aim to address similar issues in a wide variety of contexts.

## 27.2 Literature Review

### *27.2.1 Technology in Schools/Curricula*

Educational research has often focused on the video game as a location for learning, such as James Paul Gee's description of video games as learning environments where learners explore through trial and error and at their own pace (Gee 2013). This trajectory of research into these kinds of digital games examines the qualities of computer and video games, what kind of "good learning" occurs through the play of "good games" (Gee 2007). That said, Gee identifies that it is not enough to use games in school but to make learning more "game-like," not via the form of games but rather the learning principles used "when and if they are playing ... reflectively and strategically" (Gee 2007). In this mode, game play is an experienced, situated learning as learning occurs within the moments of play by, guided by the game through in-game scaffolding such as level design, tutorials, and difficulty levels (Gee 2004). If school could be like games, Gee argues, then all learning would be more situated within appropriate contexts: students would put on professional identities (e.g., scientists). The (game) play is important here as a means for eliciting these identities, while the teacher (or someone or something else) would guide the learner in appropriate activities.

Previous research into using games for learning in formal educational contexts has been either in the development and use of custom games for specific content needs (Jenkins et al. 2003; Ray et al. 2013; Jong 2015) or the use of existing COTS games (Squire 2005; Steinkuehler 2007; Wiklund and Ekenberg 2009; Miller et al. 2012; Gerber et al. 2014), often originally designed for entertainment rather than education (Sandford et al. 2006). The typical school as described by Jenkins et al., i.e., the school that uses digital gameplay in the classroom and embedded throughout curriculum, has come to fruition in some locations (Tekinbaş 2011; Dikkers 2015) but is facing a number of challenges as the practice spreads and is adopted by educators (Groff and Mouza 2008; Takeuchi and Vaala 2014; Admiraal et al. 2014), especially in various transnational contexts (Hainey et al. 2013). Games are judged on their appropriateness to the content in varying ways but often based on whether the specific gameplay within the game fits the learning needs or researchers are met with teachers with varying perceptions of using games in the classroom (Gerber and Price 2013; Mifsud et al. 2013; Dickey 2015; Sáez-López et al. 2015).

### *27.2.2 Limited Aspects of Educational Content*

Other strategies to integrate COTS games in classrooms have appeared in recent years (Charsky and Mims 2008; Charlier and De Frahne 2012; Bourgonjon et al. 2013; König et al. 2014). Indeed, in the previous volume of *Serious Games and Edutainment Applications*, authors Kae Novak and Rurik Nackerud outline an adoption model for evaluation and implementation of COTS games in curricula. Their focus was in evaluating games based on immersion – how focused were the gameplayers on their own gameplay (Novak and Nackerud, 2011) by creating a rubric that connected the concepts of flow (Csikszentmihalyi 2014) to motivation (Keller 1967; Malone and Lepper 1987) while also considering ease of use for the students (Novak and Nackerud 2011, p. 301). This rubric is designed to find games that would prove enjoyable to play by students; only one of the six qualities tracked for the games connected to educational value, whether the game is applicable to learning objectives (p. 300). It also assumes a particular mode of game use: to play as it was intended, rather than in a subversive or critical mode, playing around and between the boundaries set by the game (Flanagan 2009). That said, they identified a number of types of learning that similar games could be connected to, not just in STEM content categories but also in humanities (history, language arts) and business (Novak and Nackerud 2011, p. 305).

This model situates the game as a lens through which other activity occurs, rather than the focal point of the lesson. The following are such other activities that we explored in our pilot sessions (described later in this chapter):

- Group simulation games and "role-play": pinpointing how group decisions are made
- Narrative games and "detective play": overhearing conversations to provide writing prompts
- Fiction and world building as a means to understand history
- Motivation and alternate means of expression
- Inspiring curiosity through counterfactuals

In the cases described in the literature, games are directly oppositional (at least as a class activity) to the rest of standard curricula, and games are not played in the same manner as they would be in self-directed play. Game play is situated within constraints of the classroom, and for this, we needed to more deeply consider how specific classrooms lead to particular constraints.

## 27.3 Research Methods and Process

The proposal for this 2-year project was generated in the fall of 2013 and commenced in the fall of 2014. We assembled a team including the principal investigator, a project manager, and two graduate student research assistants enrolled in MIT's Comparative Media Studies and Writing Program. At the beginning of the project's second year, two MIT Game Lab instructors with professional interest in gaming and the humanities joined the team, replacing one graduate researcher upon graduation.

It was our hope that we would not only create stand-alone lesson plans that high school humanities teachers might use in their own classrooms but to develop a framework that teachers and educational technology coaches might use to design their own game-based learning activities based on their own learning goals. To this end, we knew it would be important for us to be working directly and codesigning our research with a few local area (metro Boston) school districts. We reached out to a few local school districts with varying degrees of success, due to conflicting academic and accountability pressures, time, and research fatigue. In the end, we formed relationships with two school districts: Lynn Public Schools (Years one and two) and Wakefield Public Schools (Year two). We worked with the administrative team from Lynn Public Schools in a codesign model incorporating input from key stakeholders including teachers, educational technology coaches, and district-level curriculum and instruction administrators. The relationship with the Wakefield Public School District was teacher driven and then incorporated school and district administrative support.

Over the course of several months, we met with members of the Lynn Public School District administrative team, outlining our objectives for the research, expectations for participating schools and teachers, and a process for moving forward. Lynn Public Schools provided a unique opportunity for us to engage with a diverse local school district that also operated four schools serving varied student populations, representing traditional college-preparatory high school curricula, a vocational/trade school curriculum, and an alternative, combined middle/high school experience supporting at-risk (i.e., underperforming and/or underserved) students. Meetings with district-level curriculum and instruction administrators addressed administrative concerns while also identifying opportunities to collaborate with specific teachers across the four schools. During these conversations, we asked many questions of school and district administrators that helped us to define design constraints and priorities from the district's perspective.

After setting priorities (discussed in greater detail below) with the district-level staff, we spoke with each of the school principals individually. Again, we outlined our research goals and objectives and expectations for school participation and discussed the process for moving forward. In addition, we asked principals about their hopes and their concerns, which always reflected the priorities outlined at the district level. Each principal then worked with their team and the district office to identify which eight teachers would participate in the project as codesigners.

The eight teachers selected to participate in the project did not necessarily identify as game playing or as deeply familiar and comfortable with technological tools, although some were both or either. Teachers were selected and opted to participate via their willingness to try new things in their classroom. For some, this willingness came from a supposition that games have a potentially powerful role in the classroom. But for most, that willingness came from an ongoing desire to identify and use instructional strategies that motivated students to engage more deeply in their classroom and curricular content.

### *27.3.1 Research Design*

The project was conceived as design-based research initiative with the eight teachers noted above serving in the role of codesigners. That being said, we also needed to manage and limit the level of time required by participating teachers. As a result, we opted to focus the collaborative design work of the teachers specifically on the development of lesson plans that could be developed and implemented within the 2014–2015 and/or 2015–2016 American academic years (which run from late summer to early summer, around August to June). Through this narrow focus for each of the teachers, we hoped to yield several key pieces of data, including generalizable lesson plans, specified design constraints and implementation strategies, and documentation of the design and planning processes.

With this understanding, the team drafted a research and design plan for working with teachers to codesign lesson plans or units of study that would uncover the aforementioned data while also building teacher capacity to design their own game-based learning instruction. To do so, we used four data collection methods to support the design, implementation, and evaluation of the lesson plans.

Phone interviews served as preliminary explorations with teachers who were already using game-based learning in their classrooms. We undertook these early in our research to uncover teachers' style, content focus, instructional objectives, and game-playing experiences as well as that of their students so that we would have a greater understanding of what worked in game-based learning-enabled classrooms and what might onboard teachers into such inclusions in their curricula. Other phone interviews were conducted with administrators from area school districts, professional associations, and state educational offices. Finally, we created a survey, and from there, we created and distributed an online survey, which invited high school humanities teachers nationally to respond anonymously online. The tool collected information about age levels and subjects taught, required texts within their curricula, any flexibility in instructional design, time constraints, experiences playing games, and logistics-oriented questions about technology and school-day structures and resources that might serve as design constraints.

Our longest running and most important method was classroom observations. These provided a structure for observing student and teacher activities for in-class play and addressed specific categories of the experience, including task comprehension, game/technology usability, student affect, and teacher and student engagement. They also required navigation of the hurdles for getting games into particular classrooms, which allowed for a situated understanding of what some of those hurdles might be. We also collected student work generated during these classroom pilots. That work included classroom conversations and any homework or in-class assignments, to be examined in terms of their connection to the game play and academic content, levels of engagement, and as examples of the specific content/skill priorities. For our final engagements in each iteration of the classroom observation, we conducted post-lesson interviews with the teachers in order to solicit feedback on how they might improve upon the process, the gameplay, and student engagement. Teachers also provided insight regarding whether the student participation and work products were typical of the classes observed.

As a research project with human subjects, our team was required to be trained in and abide by ethical human-subject research guidelines. Thus, we submitted the requisite documentation (a research application, informed consent forms from teachers, informed consent forms from students' parents, and observation protocols) for review and approval by MIT's Institutional Review Board, the Committee on the Use of Humans as Experimental Subjects (COUHES). This process took some time, during which we could not conduct the aforementioned research methods. We filled this time with other kinds of preliminary research, as described in the following section.

### *27.3.2 Preliminary Research*

We began by researching the best practices among high school humanities teachers already integrating popular games into lesson plans. Our initial efforts uncovered a strong body of research, as listed in the literature review above. We sought to reach beyond this work and provide the field with a broader and "self-serve" tool or set of resources that would allow teachers in any of the humanities disciplines to design their own instruction using games, in much the same way that one might use any new text or media like popular fiction, film, documentaries, or popular television series. Thus, we brainstormed additional examples of how specific COTS games might support instruction in the humanities.

However, we had no content focus for our investigation more specific than "the humanities," as we recognized that the learning goals, rather than particular games, had to take the lead in our attempts to narrow our focus. Indeed, "the humanities" is a large, unwieldy cluster that covers many disciplines, times periods, and concepts. Thus, we needed to immediately establish our conceptualization of humanities disciplines and our goals in supporting those disciplines in the classroom, as well as how to facilitate the implementation of that support on a large scale, as this was one of the primary objectives outlined in our proposal. Did it make sense to select a few required courses to ensure all students were covered? Or might it make more sense to focus on a few concepts or skills that had more universal application across multiple subject areas? Through researching current curricula and emerging standards in high school humanities in the United States, we opted to focus on courses that all American students are required to take to meet high school graduation requirements (English, world history, and US history) to ensure that we might reach the greatest number of teachers and students.

This research consisted of our phone interviews and survey (as discussed in the previous section) and a cursory review of the programs of study and course offerings of select local public school districts. Here, we were looking to uncover whether there was a consistent course offering at the school and district levels in terms of topics, sequence, and required versus elective courses. For instance, all students must take 4 years of English. Yet, some variations exist between the structure and focus of the courses; some districts were offering traditionally tiered (i.e., remedial, standard, and honors/"gifted") course, whereas others offered English as part of a heterogeneously grouped, cross-disciplinary course taught with the history offering.

From here, we still needed to determine whether a consistent set of concepts, skills, or practices cut across these subject areas, particularly as educational models were shifting at the state and national levels. In order to contend with those shifts, which would also be of high priority to the teachers in our pilots, we examined the Common Core State Standards for High School English Language Arts and Social Studies/History. At the time, these new standards were in the early stages of adoption and implementation with significant and often heated public discourse regarding their potential impact on instruction. States, districts, schools, teachers, parents, and students alike struggled to understand how the new standards might impact classroom practice.

In particular, we considered the English Language Arts standards for concepts, skills, and practices that might apply more generally to most or all humanities areas. We talked with district and school administrators about what they thought were important and/or difficult topics or skills to teach within those standards. This was crucial, as we wanted to target those areas deemed difficult to teach, where no or few existing instructional strategies have the desired effect, rather than using COTS games to support instructional areas where proven strategies already exist. These reviews and conversations resulted in the prioritizing the following humanities skills and competencies: critical reflection (thinking and writing), argumentation, systems thinking, and problem solving. We validated the list of priorities using the phone interviews and surveys.

High-level learning goals in hand, we needed to define how gameplay might play a role in achieving them. We generated a short, yet varied list of prospective games that held some promise for use in required English and history classes while also providing opportunities to address our prioritized skills and competencies. We hoped that this list would have a broad appeal, would account for classrooms that included a diverse set of learners, and would support multiple models of integration into the classroom.

Our interviews with teachers and other stakeholders revealed that teachers (and administrators) were having difficulty imagining what a game-based lesson might look like or how much commitment such lessons would require from the teachers. Were they capable of leading this kind of instruction? What kinds of student outcomes might they observe? To address these questions, our team developed sample lesson plans to offer a few models of game-based instruction, as well as assuage any fears that we would not be considering all facets of lesson design and implementation as we moved forward.

## 27.4 Pilot Testing in the Classroom

### *27.4.1 Year One*

As previously noted, our initial concept for this project was to work with a team of teachers to codesign and implement instructional units, refine these, and then develop resources to facilitate broad adoption of the materials. However, lengthy ethical research and school district approval processes, an abnormally treacherous winter that forced many school closings, and busy state testing schedules all conspired to delay this collaborative process, especially pilot testing of the instructional materials.

One enthusiastic Latin teacher was eager to push the initiative forward. Late in the 2014–2015 academic year, we designed and tested a lesson using *Rome: Total War* in three of the teacher's Latin I classes over the course of 3 days in June, taking advantage of with the last 3 days of the academic year after the school's final tests.

Planning began with an evening phone call between the teacher and an MIT researcher, which discussed the time frame for the experiment, the number and grade of the students involved, and the curriculum of the class. The students were spending their semester reading excerpts of Gaius Julius Caesar's *Commentaries on the Gallic War*. The teacher described both the historical and linguistic curriculum of his Latin class; a game that was relevant to any subset of those overlapping domains would be appropriate for his students. Even a game about the mythology of Greece would be within bounds.

Although initial ideas gravitated a game about vocabulary and grammar, the phone call was key in revealing the teacher's own familiarity with certain game genres. Specifically, he was fond of *Age of Mythology* (Ensemble Studios/Microsoft Game Studios) and generally familiar with strategy games. He was already using films such as Ridley Scott's *Gladiator* in the class, indicating some tolerance of depictions of violence in the classroom. With the perennial popularity of Roman conquest in computer games, we agreed that this might be a fruitful lead to pursue.

However, the discussion also uncovered a technical challenge: The teacher only had access to one computer, an aging Windows PC connected to a Smart Board (a digitally interactive whiteboard) and the internet. While the school had large computer rooms, those machines were generally reserved for other classes, and the teacher was not hopeful about having an exception made for his class. Furthermore, we wanted to arrive at a solution that he would be able to use every semester and not have to rely on one-time solutions.

One possible solution would be an activity in which the students would jointly make decisions as an entire class. A turn-based game would be more appropriate than a real-time simulation. We would have two separate freshman classes, meeting for three sessions ranging from 45 to 90 min each. The school ran on a waterfall schedule, meaning we would be working with the same students at different hours on different days.

The initial phone conversation was remarkably fruitful for the effort. In about 30 min, we established clear needs and possibilities for the teacher, as well as learning about specific constraints that could be turned into a structure for the activity and gameplay rules. From this, we shared a Google Document to craft the instructions of the class activity, allowing both the teacher and our researcher to freely edit and comment. All subsequent discussion occurred through the Google Document or email up to the day of the playtest.

From here, we brainstormed specific games that might fit the needs of this class, from as broadly as genres/kinds of games about Roman civilization or mythology, language-learning games, and games more generally about organized martial combat to specific games or even particular versions or mods of games, like *CivCity Rome*, *Ryse: Son of Rome*, *Europa Universalis: Rome*, *Influent*, *Age of Mythology*, *Total War: Rome II* (*Caesar in Gaul* Campaign Pack), and what would be our piloted game, *Rome: Total War*. Knowing the limitations of the computing resources available, we quickly filtered any games that involved significant 3D graphics or relied on fine graphical details for decision-making; the low contrast of the Smart Board in the summer sun would render such information practically invisible. We also avoided games that relied heavily on real-time decision-making so that students would have time to consider and discuss decisions before committing to them. We wanted to avoid the situation where the entire class would effectively be watching a single student play a computer game in the class.

*Rome: Total War* (Creative Assembly, 2004) emerged as a reasonable compromise and a promising solution. Unlike its sequel, the game was designed for an earlier generation of desktop computing and lower screen resolutions. While the Total War series is renowned for its 3D presentation of real-time military engagements, the games also allow players to focus entirely on turn-based national management and to automatically resolve military confrontations. *Rome: Total War* also provides players with a range of options at the very beginning, which would allow us to tailor the pace and difficulty of the campaign to meet the constraints of a three-session classroom activity.

Having settled on the game, we saw in *Rome: Total War* a suggestion for a role for the students. Since the game puts the player in charge of multiple military commanders, governors, and provinces, the class could act as the senate, the governing body of the Roman Republic. This concept proved extremely generative, and our team of researchers and teacher together devised a lesson plan: Students could nominate and elect two leaders ("consuls") among their peers to enact national policy and military doctrine. Each consul would take a turn making decisions in the single-player game, while the other would keep mandates in check with the power of veto. Displaying the state of the Roman campaign on the Smart board allowed the rest of the class, the senators, to advise, argue, and orate as they had learnt from historical texts. New senators would be elected as consuls after a few turns.

This arrangement neatly addresses the contradiction of trying to engage the entire class in a single-player game. Even as we planned to use *Rome: Total War* in the classroom, it became clear we could invite the students to play a different game, this one not with the keyboard and mouse but with politics and rhetoric. The digital game would simply serve as a catalyst for senatorial deliberation. Instead of glorious conquest, we would place the emphasis on the considerations and complications of public policy.

We examined and addressed elements of the digital game would not fit with our structure. For instance, Rome: Total War describes the player as the patriarch of a powerful Roman family, controlling territory on the Italian peninsula, allied with a powerful computer-controlled senate in the city of Rome. The in-game senate usefully offers "missions" to the player as a gentle invitation to follow the trail of recorded history. Since we wanted the class to think of itself as the actual Senate of the Republic of Rome (SPQR), what were we to do with this autonomous element in the digital game?

We settled on asking the class to treat the computer-controlled senate as a local city government that offered rewards for positive actions, e.g., the successful occupation of new territory. It made sense that the city would maintain its own town guard, which explained why it maintained its own autonomous army. Historically, a single senate commanded both the republic and the city of Rome. Fictional liberties allowed us to paper over the incongruity between our pedagogical goals and the systemic model within the game.

The Google Document evolved into a comprehensive curricular activity guide, with procedures for setup, elections, senatorial proceedings, civil and military decisions, and post-activity debrief. We fully expected that the document would change after having the opportunity to play the activity with actual students. Assumptions could be disproved, strengths could be reinforced, and steps could be streamlined. However, only an actual playtest would allow us to prioritize future edits based on actual observations.

Technical problems on the first day of the three-day playtest were unsurprising. We had provided the teacher with a redemption code that would allow him to download and install the game from Steam, an online store for digital downloads. While the classroom computer was certainly up to the task, the school internet firewall prevented the download of the game. Fortunately, we had an extra laptop with the game already installed, but it was unable to send video directly to the Smart Board. Rerouting the video cable from the classroom computer to the laptop resolved the issue.

While we expected the teacher to lead the class, these eleventh-hour problems were symptomatic of a root cause – the teacher was not able to actually install and play the game prior to the playtest session and thus had no opportunity to test it with the Smart Board. The MIT researcher and the teacher agreed to salvage the classroom activity by having the researchers operate the laptop, convey the rules, and explain senatorial procedures. This freed the teacher to participate in the class activity as a Socratic mentor, listening to all the arguments brought by the students and introducing questions to probe their reasoning. The teacher also maintained his intended role as the commissioner of the consular election.

In the first day, both freshman classes took most of the class session just to get through a turn of gameplay. The consular elections took a great deal of time, largely consisting of students declining nominations by their peers. It soon became clear that any two students willing to actually take a leadership position would automatically be the first consuls. Despite its clumsiness, the election process felt playful with a lot of good-natured ribbing among the students about who might be the best dictator. It may have also helped the consuls feel confident in their mandate to decide on behalf of the class, because everyone else had clearly indicated their reluctance to take a leadership role.

This playfulness was quickly met with confusion. The very first turn of *Rome: Total War* introduces a large amount of new information with little context: military units, city budgets, and missions from the computer-controlled senate. However, all that information is provided in windows that occupy the majority of the screen and do not change until the mouse is clicked. This gave us the opportunity to explain each screen in detail and describe the options before the senate, as well as the possible outcomes of each decision.

*Rome: Total War* has a "fog of war" feature that hides portions of the world map at the outset. Moving troops, diplomats, and ships in to unexplored territory reveals cities, armies, and geography. In most playtests of this activity, the first actual decision of the consul would be to move one of their units as far as possible into the unknown or to send a diplomat to another town. This is a low-risk decision that the class found easy to justify and usually rewarded with a surprise that resulted in discussion among the students.

In both classes, the discovery of the Carthaginian navy off the coast of Sardinia or troops in Sicily resulted in a vocal eruption among the students. The teacher seized on the opportunity to connect the events of the game to the content of the class, asking questions like, "What is that island? Why is Carthage there?" Rome's historical relationship with Carthage is both aggressive and memorable, and by dovetailing the momentary surprise with knowledge gleaned from earlier in the semester, the teacher could gain useful insight into what students had retained from their readings.

The next big surprise always occurred after a siege. When a Roman army successfully occupies an enemy city in Rome: Total War, the game presents the player with the option to occupy, enslave, or exterminate the population. Students responded differently to the sudden moral dilemma, some mathematically weighing the economic and political benefits of each decision, some arguing for the ethical ramifications while correctly suspecting that leniency would come with a game penalty. Some declared nihilistic intentions with glee, and some just sat back, amused at how seriously everyone else was taking the game.

This was a clear example of the varied freedoms that games give license to in a classroom (see Klopfer et al. 2009). Students felt free to play with their identity, to choose not to engage with the fiction, to coolly experiment with the ideas of the game, and to adopt a losing stance. After the three-day playtest, the teacher noted that he was worried that the gameplay might overwhelm his pedagogical goals and that it was a pleasure to see students demonstrating their grasp of the material and engaging with it in a different setting.

### *27.4.2 Year Two*

The second school year gave us the opportunity to iterate on the rules of the senate role-playing game, iron out technical problems, and run the test with different students. The teacher was also able to use the summer recess to familiarize with the subtleties of the game. Of particular concern for us was addressing the reduced agency students experienced when they were not consuls. Should we have them prepare speeches? Should we break them into discussion groups? Would homework be appropriate?

Our revision had the teacher entirely leading the session, with the MIT researchers simply observing. Technical issues were resolved by providing the teacher with a boxed copy of the game rather than relying on digital downloads. Noting the presence of Carthage in the game, the teacher wished to run the game with a cohort of juniors who had just read accounts of the Punic Wars. Between sessions, students would be given an assignment to write a few paragraphs proposing policy for the consuls to consider. We also proposed a separation of responsibilities for the consuls and more structure discussion.

Compared to the playtest in the first year, the juniors seemed less animated. The "improved" nomination and discussion structure seemed to dampen much of the spontaneity seen in the freshmen, stretching out the processes of election and discussion twice their duration. Consular terms lasted even longer, allowing fewer students to take the reins of the republic. The mid-semester schedule may also have introduced confusion about whether the game was intended to be playful or the first part of a serious writing assignment. This stood in stark contrast with the post-finals, low-stakes scheduling of the first playtest.

Despite these differences, students still showed a high level of engagement. Some rushed through their lunch break to return to the class and argue over the merits of hewing too close to actual history. Many turned in remarkable papers, reflecting on the decisions of the class and exploring "what-if" scenarios. The teacher followed up with an invitation to run and observe the game with a senior class. Between the three playtests and another chance to rewrite the rules of the game, we hope to unshackle some of that freeform play we witnessed in the first year while keeping the thoughtful reflection of the second.[1]

[1]Another pilot session was carried out late into the writing of this chapter. As such, our analysis of that session is ongoing and does not appear here.

## 27.5 Development of Scalable Resources

In addition to informing our design process for each particular lesson, the pilot testing of subject-specific lessons also contributed to our evolving understanding of the resources and materials we aimed to develop and test in the project's second year. These resources were to be our main output from the project and contribution to COTS game usage in classrooms. Yet, our initial research and first pilot sessions unearthed more questions, rather than solving them:

- What other models of implementation might be used to support a more engaging experience with a game?
- What specific resources might another teacher need to implement this in another kind of classroom, such as a world history class?
- Would other teachers be able to overcome technical, logistical issues, especially around accessing a (downloadable) game?
- What criteria should be used to generate a list of games and lesson plans?
- With (American) schools' increasing adoption of tablet technology, should we focus our efforts there?
- If complex systems and persistence are important, should we focus on "immersive" games, and what constitutes such games?
- If teachers will be ultimately leading these activities, how do we know what game features will be important to them?
- Which popular games might support school-based play, and in what models might these games be used?
- What support might teachers need to develop their own lesson plans using other COTS and unique instructional objectives?
- What resources were required to support interested teachers that would not have the instructional design support of a team of MIT researchers?

The proliferation and complexity of these questions, as well as the specificity needed to answer them, which conflicted with our scalability goals, led us to consider how we could create a resource for guiding teachers through the bevy of constraints, logistical issues, game choices, and curricular needs that we had encountered. We began calling that resource a framework, i.e., a methodological, step-by-step tool, for teachers to guide them as they design their first forays into implementing COTS game-based learning in their specific classrooms.

### *27.5.1 Framework Design Process*

Drawing upon our team's experience designing games for use in classrooms, we were well aware of many potential barriers to entry for teachers hoping to implement game-based learning; some of these barriers are discussed in Chapt. 10 of this volume, "Tipping the Scales: Classroom Feasibility of the Radix Endeavor Game."

As we prepared to work with teachers to develop a series of sample lesson plans, we unintentionally found ourselves defining and documenting an instructional design process for game-based learning. Since we did not yet have a specific teacher and their corresponding design constraints driving our work, we continued to design for more general application in the high school humanities classroom. The result became the first phase of our framework design, a whiteboard showing the messy brainstorming of potential design constraints to consider: subject and content, skills and competencies, technology access and resources, modes of play, pedagogical use, game genre, and time available.

Each constraint alone could influence the instructional design, but how might we build and support a process that could account for all of the constraints together? We imagined many ways of allowing teachers to account for and interact with these design constraints, such as a multi-axis table, a list of these factors, and a suite of sample lesson plans illustrating the varied possibilities. In the end, we decided to present the status of our work as a “working example” (i.e., a flexible submission format meant to facilitate constructive discussions on works in progress) at the Games + Learning + Society 11.0 Conference in Madison, Wisconsin, in July 2015 and solicit input from researchers, designers, and teachers in attendance.

We presented our progress from the first year of our project and posed a question to our session’s attendees: What should the end product look like? The feedback varied widely. Some attendees offered or sought further ideas for the instructional use of using game titles, while others were not sure how our project differed from more theoretical work on COTS games in the classroom. Others expressed concern that we would not be able to achieve codesign with teachers, due to the prohibitive time required to work in a collaborative setting. Others still acknowledged the inherent tension between trying to find games and activities that were teacher- and class-specific yet generalizable to a national and international audience. Ultimately, participants confirmed our suspicions that our most important task involved not winning teachers over to games but working to expand how teachers are approaching the relationship between learning objectives, games, and their role in the classroom as facilitators.

With this feedback in mind, we continued to work through the iterative design process around the framework, discussing it with teachers, peer researchers, and each other. We aimed to bring some structure to the instructional design process that would account for a wide variety of instructional settings, was easy to implement, would encourage rather than discourage teachers, and would integrate some level of playfulness.

#### 27.5.1.1 Card Deck

We created a color-coded card deck, which constituted the second phase of our framework design process. Each color represented a category of design constraint and included enough cards to cover potential design constraints as well as one blank card to accommodate teacher-specific concerns. The categories and constraints were as follows:

Subject and content: history and social studies (government/civics, us history, world history, economics, art history), English/language arts (literature, writing, vocabulary/grammar, Classics), arts (visual, music, design, drama). Skills and competencies: critical thinking/reflection, problem solving, complex systems, persuasive writing and argumentation, perseverance and grit. Technology access and resources: BYOD (bring your own device policies that allow students to use personal devices in classrooms), 1:1 (policies through which students are provided with a particular device that they use throughout an academic term), laptops or tablets (often in the form of a cart, owned by the school, with a classroom's worth of devices that can be borrowed by a teacher for a class session), computer lab, one computer in a classroom, available platforms (console, browser, tablet, phone, PC/Mac download). Modes of play: full class, teacher-facilitated play; small group work in class or in a computer lab; individual play in school; individual play outside of school, either at home or in community spaces. Pedagogical use: context-setting for new material, instructional delivery of new material, repetitive skills practice (commonly known as drills), assessment and/or synthesis of learned materials. Game genre: strategy (real time or turn-based), role-playing, platforming, text-based, shooter or action, puzzle, point-and-click, adventure, shortform/casual. Time available: semester/trimester, unit (a block of class sessions), week, class session. Game selection criteria: student-selected, teacher-selected.

Teachers would use the card deck to drive their learning as well as the instructional design processes. The card deck would force the designer to consider potential constraints and select the cards that best matched their own objectives. Teachers would then be able to design a lesson that would meet their instructional objective.

We tested the card deck at the Media Literacy and the Power of One Conference in November 2015. Session participants were divided into groups with a set of six cards, chosen at random from each of the six categories described above. First, they were asked to spend 5 min listing all of the games they could think of that they or their students enjoyed playing. This exercise allowed the participants to introduce themselves and their experiences of playing games and observing student gameplay trends. Then they were presented with a scenario and a task: They were to play the role of a high school English or history teacher and plan an upcoming lesson, for which they needed to create a game-based learning activity that would meet their instructional objectives while fitting the design constraints dictated by the cards.

Within minutes of starting the lesson planning activity, it became clear that a couple of the cards were preventing groups from making progress, particularly the game genre cards. Once we removed the game genre constraint, the groups easily resumed the activity and were able to generate plausible game-based learning activities that met their instructional objectives and could be implemented using the defined technology resources and time allocation. For example, one group created a lesson for a freshman English class reading Homer's *The Odyssey*. In addition to reading the text, students would play the classic PC game, *The Oregon Trail*. Their summative assessment would be to create a game design document on how they might create a similar game for *The Odyssey*.

While the exercise did not yield a breadth of lesson plans, it did reveal crucial shortcomings of the prototype card deck. As noted above, game genre posed problems for groups, even halting the instructional design process in some cases; this could be due to introducing a specific game genre too early in the process, or that game genre was not as structuring a constraint as the others. Additional feedback suggested that the time commitment (year, semester, week, one class period) cards were also not necessary in the early planning stages. The more we talked with participants, the more we realized that the categories to include from the outset were highly personal. For some, time was of greatest concern, and, for others, the mode of play was of utmost importance.

#### 27.5.1.2 Mat

As we entered the third phase of the design process, we focused on the usability of the framework. In our testing at the Media Literacy and the Power of One Conference, we had only given the group a small number of cards one from each category. While this was a useful exercise in understanding how teachers might design instructions for a particular set of design constraints, it was not particularly useful in understanding how teachers might use the card deck individually and in a more freeform model. Initial feedback indicated that teachers would need greater context and support to use the cards effectively. After brainstorming and vetting many possible iterations, we developed a mat, fashioned after existing card games that use a game mat to help structure play (Fig. 27.1; shown in use in Fig. 27.2). We thought this format might help provide the necessary structure to support using the cards as a planning tool.

Our playtesting of the card/mat combination uncovered a number of challenges with the design, as explored in our testing notes below:

Context: Testers needed additional instruction about the task at hand. It was unclear exactly what they were designing was the center of the design the game or the instruction or some combination thereof.

Vocabulary: The language used both on the cards and in the verbal instructions were unclear to some testers. As examples, the term COTS and the modes of gameplay were confusing. Testers asked whether there might be a need to embed professional development into the activity in some form and suggested putting definitions or examples on the card deck.

Prioritization: Testers were overwhelmed by the amount of information they had to consider in the planning process.

Fixed factors: The game mat presented all of the categories in equal weight. Testers pointed out this would not be the case in reality. For example, a teacher might not have any control or influence over the technology resources available to students. They called for a way to differentiate factors that were pre-defined or beyond the teacher’s control or versus those that they could influence.

Optional Priorities: Testers wanted the capability to add categories that were unique to their instructional goals.

Discounted factors: Testers also asked questions about whether they were required to address all of the categories. They suggested including a number of blank

**Digital Games in the High School Humanities Classroom**

| | | | |
|---|---|---|---|
| **Instructional Time**<br>Academic Year<br>Semester<br>Term<br>Unit (6-8 Weeks)<br>Unit (3-4 Weeks)<br>Week<br>Multiple (2-3) Class Periods<br>Class Period - Long Block<br>Class Period - Standa[rd] Block<br>Ad Hoc As Time Allow[s] | **Technology Platform**<br>1:1 iPads<br>1:1 Laptops<br>BYOD<br>Chromebooks<br>Laptop Cart<br>Playstation<br>Wii<br>XBox | **Game Play Location**<br>Computer Center in Classroom<br>Computer Lab<br>Home<br>Library<br>Teacher's Computer Projection in Classroom | **Group Size**<br>Individual Play - Alone<br>Individual Play - Group<br>Setting<br>Pairs<br>Small Group<br>Full Class Play |
| **Relationship to Instruction**<br>Pre Instruction Context Setting<br>New Content Instruction<br>Post-Instruction Application<br>Post-Instruction Sk[ill] Practice<br>Post-Instruction Assessment | **Game Genre**<br>Short Form/Casual<br>Role-Playing<br>Puzzle<br>Shooter/Action<br>Strategy<br>Simulation<br>Story-Based<br>Point and Click | **Game Selection Criteria**<br>Student Selected<br>Teacher Selected<br>Key Words List<br>Historical Time Period<br>Literary Theme<br>Learning Standards | **Student Product**<br>Game Design Document<br>Persuasive Writing<br>Reflective Writing Journal<br>Individual Presentation<br>Group Presentation<br>Small or large Group Role Play |

**Fig. 27.1** The Game Mat shows all of the potential criteria a teacher might use

cards that could cover any categories that they did not want to address or consider upfront.

Search/Selection Criteria: Testers wanted to understand how to determine their selection criteria, via subject matter (as opposed to more specific categories like "historical time period") or keyword search terms (which could be a write-in category and could prepare users for external searches).

Testers also suggested categories they thought were potentially important but missing from our design:

Sound/audio: Testers indicated that games that have sound as a critical component of the gameplay might require additional equipment and set-up time. Teachers would need to consider this factor as they planned their lessons.

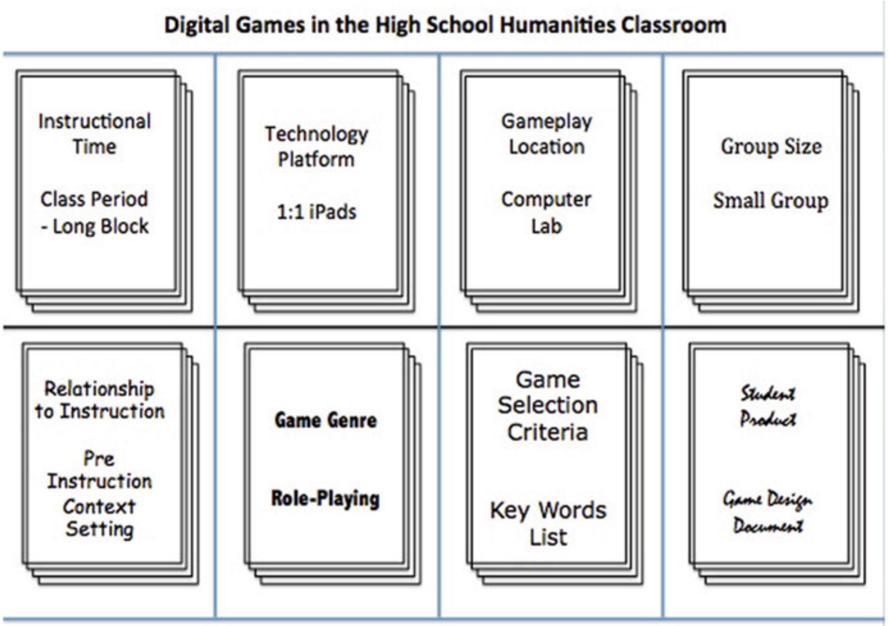



**Fig. 27.2** A completed game mat provides the foundation for teacher’s research on selecting a potential game for classroom instruction

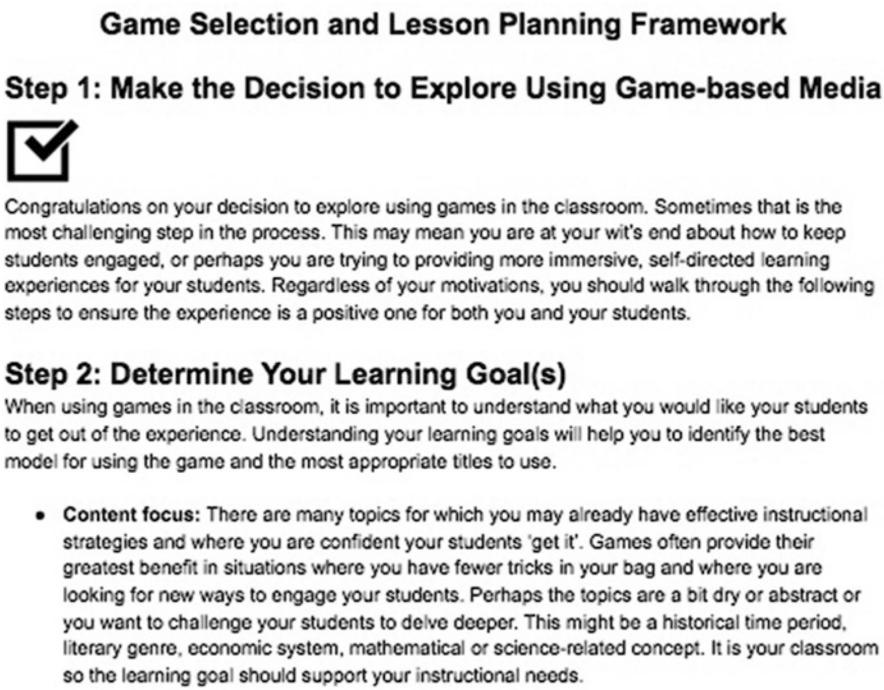
Game quality: Testers wanted to know more about the quality of the game. The term “quality” was discussed at length. For some testers this meant having data regarding the effectiveness of using the game for educational purposes. Other testers considered included level of engagement, “immersiveness” (a term which is not fully clear here or in other conversations about games and media), and whether a game is factual (i.e. historically or scientifically, although testers also noted that in some cases, the use of a game that drifted from historical accuracy had a potentially meaningful place in the classroom, especially if students were asked to identify inaccuracies as part of their gameplay experience).

Developmental Appropriateness: Age ratings were a concern with testers noting that some schools would not allow teachers to use games rated Mature (deemed appropriate only for players age 17 and up) in the classroom.

Preparation time: Testers noted that lesson time was not the only time that could be constrained, as there could be logistical/setup time, as well as the learning curve for teachers and that for students.

Sequence: Testers also wondered if they should think about these factors in a particular order. Many questions arose about when and how they might consider specific factors.

The testers recommended that the mat/resource would appear in a digital format, perhaps as a searchable database or a similar research tool, which could then include



Game Selection and Lesson Planning Framework

Step 1: Make the Decision to Explore Using Game-based Media

Congratulations on your decision to explore using games in the classroom. Sometimes that is the most challenging step in the process. This may mean you are at your wit's end about how to keep students engaged, or perhaps you are trying to providing more immersive, self-directed learning experiences for your students. Regardless of your motivations, you should walk through the following steps to ensure the experience is a positive one for both you and your students.

Step 2: Determine Your Learning Goal(s)

When using games in the classroom, it is important to understand what you would like your students to get out of the experience. Understanding your learning goals will help you to identify the best model for using the game and the most appropriate titles to use.

- **Content focus:** There are many topics for which you may already have effective instructional strategies and where you are confident your students 'get it'. Games often provide their greatest benefit in situations where you have fewer tricks in your bag and where you are looking for new ways to engage your students. Perhaps the topics are a bit dry or abstract or you want to challenge your students to delve deeper. This might be a historical time period, literary genre, economic system, mathematical or science-related concept. It is your classroom so the learning goal should support your instructional needs.

**Fig. 27.3** A digital version of the framework guides teachers through a process while also educating users about effective game-based learning practices and resources

embedded, additional research materials. In addition, testers wanted a more linear process to walk them through the instructional design process.

#### 27.5.1.3 Online Tool

In order to address our testers' call for both a digital and more linear process that might minimize the complexity of the multidimensional matrix we had presented, we generated an online tool that walks teachers through a design process. Each step in the process provides some level of professional development or background information that helps users understand the possibilities while also asking thought-provoking questions that would allow teachers to integrate their unique instructional objectives and make the experience their own (Fig. 27.3).

The remainder of Year Two of the project will engage high school humanities teachers in using the digital tool in a self-serve model to design their own game-based learning lesson plans. We will continue working with teachers to understand how the framework supported or hindered their planning and implementation of game-based learning in their humanities classrooms.

### *27.5.2 Future Possibilities*

The form of these resources is still under development at the time of this chapter’s publication. Through our iterations on and testing of that form, we are now considering a variety of possible formats for supporting our online tool, including an online database (as suggested by our mat testers) and/or guided experience, which presents the constraint categories of prompts to be filled by the user. When complete, the tool and its supporting materials could produce a sample lesson plan (via procedural construction), or a curated list of similar lesson plans for inspiration, including particular games that could fit that user’s needs. This tool could be accompanied by additional professional development resources, such as an online course which might include a series of explanatory videos and live, interactive question and answer sessions, as well as further guidance through the tool.

This would be an ambitious undertaking but one that could come to fruition both through our team’s further work and through collaboration with educators and researchers across contexts and expertise. Then this tool and its supporting materials could join the databases for games and game-based learning that exist currently and those that have yet to be developed, resulting in a rich, multifaceted, accessible, and collaborative suite of tools for helping educators navigate their various constraints in order to realize the many potentials of game-based learning.

## 27.6 Reflections and Conclusions

As noted in our introduction and as apparent from our research process, our project changed significantly over its course. The beginning stages of our research rested on what seemed like a foundational assumption: Researchers and educators before us had convincingly espoused the ways in which COTS games can be uniquely engaging and otherwise beneficial to students’ learning in the classroom. As such, teachers are often interested in implementing COTS game-based learning and (merely) need to be pointed in the direction of the right games for incorporation into new lessons within existing curricula. However, at each step of the way, we were reminded of the staggering complexity and variety of classrooms, from teachers’ great needs to their strained resources, from varying teacher expertise to expanding student literacies, and the myriad of other challenges and possibilities in between. We were also reminded that the road for this kind of research is never perfectly paved; we faced setbacks that are not uncommon in such research but did affect the extent of our capacity for codesign and our opportunities for testing.

Yet, where our project ended up looks much like our original formulation of it. Our original goals of creating resources designed from collaboration and testing with teachers has been maintained, and we have seen several iterations of those resources. Those iterations, however, have not yet found their conclusion, a scalable, accessible tool for educators looking toward using COTS games in their classroom.

Thus, our research has not yet landed on its key output, but its current status still, we feel, has much to offer other researchers in our field and area. Our research has followed a methodology drawing from rigorous qualitative social scientific methods, which extract broader patterns from the particularities of its subjects. Our choice of research site has provided rich data that speak to the problems faced by educators in a changing educational context, problems like those underlined in a recent report from the Joan Ganz Cooney Center. Their survey found teachers to be at a loss for bringing games into their classroom, an often solitary, against-the-grain undertaking that suffers from "the lack of a common source for those seeking best practices in using digital tools" (2016). Although our research is deeply and necessarily situated in our specific context, the barriers we encountered and the resulting shifts in our design process can be revealing for all who seek to support teachers who wish to put game-based learning research into practice in their classrooms.

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# Chapter 28
# The Role of the Teacher in Game-Based Learning: A Review and Outlook

**Gerhard Molin**

**Abstract** This chapter looks at the role of the teacher in game-based learning to contribute to current understanding of the agentive role of the teacher in game-based learning. There is a current trend to use digital games as tool to engage students and to enhance the learning experience in the classroom; the game-based learning discussion mainly focused on how to empower students in the classroom. Thus, the objective of this chapter is to address the role of the teacher and the most dominant obstacles in game-based learning and teaching. The chapter will illuminate and review the multiple roles the teacher currently performs in game-based learning. Moreover, this chapter will draw on Goffman's frame analysis and teacher agency to demonstrate the implications when digital games are situated in an educational context. The chapter contends that instead of seeing the role of game-based learning to motivate and engage students, games should be viewed as an opportunity to teacher learning and empowerment, giving teachers a sense of ownership of game-based teaching and learning.

**Keywords** Game-based teaching • Game-based learning • Teacher agency • Goffman frame analysis • Game design • Digital games • Teacher role

## 28.1 Introduction

Recent scholars suggested that digital games in the classroom may be an ideal solution to engage students, to prepare current generations for the future challenges in the twenty-first century, and to bring education out of the twentieth century (Gee 2004, 2007; Kapp 2012; McGonigal 2011; Prensky 2001; Ramirez and Squire 2014; Shaffer 2007; Squire 2011; Steinkuehler et al. 2012). It is widely assumed that games can provide learners with engaging learning conditions for exploration, interaction, and knowledge creation (Louise et al. 2008). Cognitive learning theorists (Bruner 1962; Piaget 1951) support this idea by arguing that

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play-like activities promote intrinsic motivation, which enables deep learning as students find themselves spending more effort and time learning, as they enjoy the activity and use the learned more in the future (Malone 1981).

Yet more and more researchers (De Freitas 2007; Girard et al. 2013; Kapp 2012) are suggesting that we need more longitude studies that prove the effectiveness of game-based learning for learning. Moreover, an overlooked/marginalized element in the ecosystem of learning is the teacher. Teachers are seldom invited in the co-development of game-based learning solutions. Likewise, their role and participation is usually not considered in the actual game design, and research on the role of the teacher in game-based learning is still in its infancy (Chee et al. 2014; Hanghøj and Brund 2010; Magnussen 2007; Berg Marklund and Taylor 2015; Shah and Foster 2015; Ulicsak and Williamson 2010).

The aim of this chapter is to address the various obstacles teachers often face and the current roles the teacher facilitates in game-based learning. Hence, this chapter will firstly draw on existing research on the importance of addressing and integrating the teacher in game-based learning. Secondly, various surveys and studies will be used which examined the teacher's perspective on game-based learning, in order to derive main barriers teachers face when integrating digital games into their teaching. Thirdly, three empirical studies will be used to emphasize main challenges and to review current roles teachers perform during game-based learning sessions. By looking at these empirical studies, Goffman's frame analysis will be used to discuss the wider implications of situating digital games in an educational environment and how digital games, as any new policy or tool, also affect teacher's agency and sense of professional identity.

Lastly, the chapter ends with a discussion about game design and game literacy as part of teacher education and about the future design of digital games for learning/teaching. This research aims to contribute to the development of a better understanding of the role of the teacher in game-based learning and future design strategies of educational games.

## 28.2 The (Missing?) Role of the Teacher in Game-Based Learning

### *28.2.1 The Teacher as Key for Learning to Occur*

John Dewey (1938), who can be seen as an advocate of the progressive education movement, suggested that education needs to be active and interactive as well as child centered (Mooney 2013). In regard to the role of the teacher, he suggested that the teacher should observe children to develop an understanding of what they need in order to be able to offer appropriate guidance. According to Dewey, appropriate guidance does require a high degree of teacher confidence, which means knowing the child and the child's needs to ensure that experimenting results in learning experience (Mooney 2013). Hence, Dewey stated that appropriate guidance consists of the teacher's ability to provoke the mind of children by asking questions. Thus, Dewey already imagined the role of the teacher as very active in terms of their teaching and the relationship with their students.

If we look at Lev Vygotsky's (1978) concept of the zone of proximal development (ZPD for short) and the concept of scaffolding, we can project an even more active role than Dewey had imagined. The ZPD describes the distance between the most challenging task a child can achieve alone and with the help of peers, teachers, or adults. Vygotsky referred to the leveraging of the abilities of a child to achieve a more difficult task with the help of others, as scaffolding (1978). Thus in Vygotsky's opinion, good learning occurs when children cannot complete a challenging task on their own, but through scaffolding.

Therefore, in Vygotsky's eyes, the teacher designs her/his teaching in a way that allows a zone of proximal development. This implies that the teacher needs to be able to facilitate such a zone by not only designing the teaching in such way but also by actively providing guidance/mentoring to facilitate scaffolding.

More recently, Ken Bain (2004) investigated more than 70 college teachers, who were described by their student as the best teacher they ever had. The teachers were defined as having a strong impact on their students' mind-set, and some students stated that their teachers "changed their life." Bain discovered that the reason why those teachers could achieve such a positive impact on their students was due to the teacher's ability to show their students the beauty of profound learning and comprehension thereof, rather than bulimic learning (Bain 2004). Hence, these teachers were able to challenge their student's knowledge and showed them a way to find pleasure in learning. Moreover, Bain discovered that those teachers were able to create conditions for natural critical learning environments, in which learning takes place rather than simply "transmitting" knowledge (Bain 2004). This is of importance as those teachers were able to help them to find pleasure in learning, rather than seeing learning as an inconvenient necessity that is necessary for passing exams and progressing in life (Bain 2004). In such critical learning environments, students encountered "safe yet challenging conditions in which they can try, fail, receive feedback, and try again without facing a summative evaluation" (Bain 2004, p. 108).

Hattie's (2003) research about key variances in student achievements confirmed that the teacher has the most significant impact. The key variances on students' learning performance, after the student itself (50%), are not the school structure, peers, or class sizes; it is the teacher (30%) (Hattie 2003). Hattie further distinguishes between experienced and expert teachers, stating that the latter is able to:

- Identify essential representations of their subjects
- Guide learning through the use of classroom interactions
- Monitor learning and provide feedback
- Attend to affective attributes
- Influence student outcomes

Overall, the aforementioned literature highlights the role of the teacher as crucial, to create critical learning environments to promote deep and collaborative learning. Therefore, the role of the teacher in game-based learning needs to be crucial as well, which also means that game-based learning could be an opportunity to empower teaching and to create new meanings of the role of the teacher in the digital age.

### *28.2.2 Addressing the Role of the Teacher in GBL*

It is the teacher who makes the difference in the classroom and who is the most influential factor on a student's learning performance and experience (Hattie 2003). However, the current game-based learning discussion underplays this crucial role (Hanghøj and Brund 2010; Shah and Foster 2015; Silseth 2012).

Recent scholars argue that teachers are key to the success of video games as tool to motivate students and promote deep learning (Kenny and Gunter 2011; Koh et al. 2012). Yet there are gaps in how the teacher can be empowered and supported. Teachers need to be provided with the necessary knowledge and skills teachers can integrate game-based learning effectively and efficiently in their classroom (Shah and Foster 2015; Silseth 2012).

Ulicsak and Williamson (2010) and Hanghøj and Brund (2010) suggested that it is important to start recognizing the role of the teacher in game-based learning, as teachers need to have a sense of ownership in order to be able to use games effectively. Therefore, it is suggested that "if the teacher does not take an active role when facilitating the game, and there is no purpose for using the game, then the learning will be ineffective" (Ulicsak and Williamson 2010, p. 39). Thus, Hanghøj argues that games need to be able to empower the current role of the teacher, which means to adapt to existing teaching practices, instead of requiring the teacher to adapt to game practices (Hanghøj and Brund 2010).

Watson et al. (2011) also emphasized the importance of the teacher being able to identify "teachable moments" during gameplay, which is yet another challenge experienced by many teachers due to their lack of knowledge and skills. However, this also highlights shortcomings of currently used games in game-based learning, as teachers have to adapt to game practices instead of vice versa. Furthermore, Eastwood and Sadler (2013) support Watson's argument by stating that it is of importance to provide guidance for teachers to make connection between the game and their teaching. Though Eastwood and Sandler also argue that this support and guidance needs to be of systematic nature, hence, schools and educational facilities need to provide the necessary professional development and tools to support teachers in acquiring the required knowledge and skills in order to effectively integrate games in the curriculum (Eastwood and Sadler 2013). Silseth (2012) underlined these arguments in her study, in which she documented the different roles teachers performed while using games for learning/teaching. Shah and Foster (2015) summarized the most pivotal roles including:

(a) Expert guide to help students making connections with the learning goals
(b) Facilitator of pedagogical approaches such as instruction, discussion, and observation to provide space for reflection and feedback
(c) Connector, to help students to see and understand the relevance of their acquired knowledge beyond the classroom

Teachers, as with any other digital technology for learning, are pivotal when it comes to meaningfully using games for teaching and learning. Hence, teachers, as the primary drivers for new educational innovations, have "... the potential to augment the effect of games on students' interdisciplinary knowledge construction and motivation to learn" (Shah and Foster 2015, p. 242).

At a panel discussion at the IDC 2004 Conference, Marvin Minsky and Alan Kay mentioned that children feel demotivated if teachers assign them something that they (teachers) don't do by themselves (Kestenbaum 2005). Hence, this indirectly signals disinterest which can result in disengagement. Moreover, Minsky and Kay also highlighted the importance of "learning by copying the way more knowledgeable and experienced people think and complete a task" (Hourcade 2008, pp. 284–285).

### *28.2.3 The Marginalized Role of the Teacher in the Design of GBL Applications*

Teachers who are interested in game-based learning are often facing several challenges that make a meaningful and effective implementation of game-based learning in their classroom difficult. Several occurring challenges and barriers can be identified, when we look at several recent scholars (Kenny and Gunter 2011; Koh et al. 2012; Razak et al. 2012; Shapiro et al. 2014; Silseth 2012; Takeuchi and Vaala 2014; Ulicsak and Williamson 2010; Watson et al. 2011), who investigated game-based learning from a teacher's perspective and what barriers often hinder the integration of game-based learning. Thus, there is a strong body of evidence that suggests that:

- Teachers only have a limited time to prepare and play a game for game-based learning.
- Teachers feel uncertain about using games in the classroom due to their limited knowledge of digital games.
- Teachers have difficulties identifying appropriate assessments.
- Teachers have difficulties integrating video games effectively and efficiently in their classroom.
- Teachers have difficulties choosing appropriate games for teaching.
- Students have difficulties to connect the acquired knowledge in a game and real-world learning.
- There is a lack of support by the school/administration to support and enhance their competences in game-based learning.

- Poor technical infrastructure, inadequate resources, and high game or licensing costs make it difficult to meaningfully apply game-based learning.

Moreover, if we look more closely at several of the aforementioned studies (Shapiro et al. 2014; Takeuchi and Vaala 2014; Wastiau et al. 2009), we can identify a repeating pattern. The greatest barriers so far have been the insufficient time, high costs, lack of tech resources, difficulties finding games that fit curriculum, and not being sure how to integrate games in teacher's teaching. Therefore, it can be argued that these findings are a strong indicator that the role of the teacher in game-based learning has been marginalized/neglected when it comes to the development of game-based learning applications. Thus, I suggest that game developers need to not only include teachers in the development process but also design games in a way that teachers can easily adapt those games to their needs. Therefore, it is important to highlight Ehn and Kyng's (1987) view on participatory design, which emphasizes the importance of genuinely including important stakeholders in the development or design process of new tools for their environment. Hence, for developing novel game-based learning approaches for the classroom, the designer should not only include primary drivers in the design but also learn from and about them, to create genuinely novel and realistic innovations (Leinonen 2010).

### *28.2.4 Teacher Education and Professional Development in GBL*

To enable an effective and meaningful integration of digital games for learning and teaching, we can argue that it will also require that schools and universities start to provide professional training and courses in game-based learning, as part of teacher's education. Yet, according to recent scholars (Franklin and Annetta 2011; Shah and Foster 2015), teacher education in game-based learning is still in its infancy. This is somewhat of a missed opportunity as a recent study by Kennedy-Clark et al. (2013) showed that teachers reported a positive shift in their ability to integrate ICT, the knowledge of games for learning, and the perception of how to integrate games into their teaching, by undertaking preparations, such as workshops, which focused on the integration of digital games for inquiry learning. Hence, a lack of knowledge on how to integrate games in teacher's teaching often leads to ineffective methods such as applying games via, e.g., trial and error (Kenny and Gunter 2011; Takeuchi and Vaala 2014). Consequently, scholars have argued that teacher education in game-based learning, as it counts for all kinds of new educational technologies/tools, will be pivotal in order to successfully and meaningfully use games as teaching and learning tool (Kenny and Gunter 2011; Koh et al. 2012; Shah and Foster 2015).

More recently, Shah and Foster (2015) have developed the GaNA (Game Network Analysis), which is a framework that aims to empower teachers by supporting them to enhance their competence, skills, and knowledge on game-based learning. Even though the crucial role of the teacher has been widely overlooked in the game-based learning discussion and is still in its infancy (Shah and Foster 2015), this recent attempt shows that research begins to focus on how to empower the teacher in their classroom through tools or frameworks in order to meaningfully merge technology and education.

## 28.3 Emphasizing Challenges and Reviewing Current Roles of the Teacher in GBL

The previous section highlighted that the current games for learning discussion underplay the role of the teacher when using games in and for an educational context and purpose. Not only has the teacher been marginalized in the design process of game-based learning applications but also overlooked in the game-based learning research community (Bourgonjon and Hanghoi 2011; Chee et al. 2014; Magnussen 2007; Berg Marklund and Taylor 2015; Shah and Foster 2015).

Hence, we can derive two dominant obstacles from the previous section. Firstly, the teachers' role is barely addressed in the design process of games for learning. Secondly, teachers often lack of sufficient knowledge about digital games and game literacy to effectively implement games for learning and teaching.

In order to emphasize and further discuss these challenges, three empirical studies will be used to review the current roles of teachers in game-based learning. Additionally, Goffman's *Frame Analysis* (1974) will be used as theoretical tool to derive a better understanding of the implications when digital games are situated in an educational context.

The first study was conducted by Rikke Magnussen (2007), who investigated the several roles teachers performed while playing, with their students, the learning game *Homicide*. In this game children take over the role of forensic experts to solve a murder case, whereas teachers alternate between fictional roles and supervisors.

The second study was conducted by Björn Berg Marklund and Anna-Sofia Alklind Taylor (2015), who illustrated the many roles teachers performed when using, in this case, *Minecraft EDU* and the challenges, among others, technical practicalities, and teachers' lack of sufficient game literacy.

The third study was conducted by Yam San Chee, Swati Mehrotra, and Jing Chuan Ong (2014), who highlighted the challenges teachers face when attempting to integrate game-based learning into their teaching such as reconstructing their professional identity.

The aforementioned empirical studies are used, because they illustrate very well the most dominant obstacles of implementing games in an educational context and address current roles of teachers in game-based learning. Also, it is important to mention that the aforementioned studies are one of the rare (Chee et al. 2014; Shah and Foster 2015) examples of empirical studies on the practicalities of using games for learning and teachers' role in game-based learning. Hence, it should be underlined that recent scholars (Bourgonjon and Hanghoi 2011; Chee et al. 2014; Berg Marklund and Taylor 2015; Björn Marklund 2014) stated that more emphasis should be laid on such studies, to develop a better understanding of game-based learning situations and for the future design of digital games for learning.

### 28.3.1 Goffman's Frame Analysis to Understand the Implications When Digital Games Are Situated in an Educational Context

When we look at the greater discourse around games as tool for learning, the concept of the magic circle is often used to describe one of the unique characteristics of games in relation to the learning experience. The magic circle was initially coined by Johan Huizinga (1949) and was then applied to digital games by Zimmerman and Salen (2004). The concept of the magic circle of a game describes "... where the game takes place. To play a game means entering into a magic circle, or perhaps creating one as a game begin ... the term magic circle is appropriate because there is in fact something genuinely magical that happens when a game begins" (2004, p. 95). Moreover, it was argued that the magic circle creates a new reality, separated from the ordinary life, based on the rules of the game and lived by the player (Copier 2007). Yet recent scholars criticized this concept (Consalvo 2009; Copier 2007; Crawford 2009) as it produces a misleading image of a magical and isolated place, which makes it inevitably difficult to understand what is really going on within such a space. The concept of the magic circle therefore should be arguably seen as a romantic conceptualization rather than an appropriate scientific theory. Thus, the concept of the magic circle should be seen as a design tool rather than a concept to use in the discourse around games and learning.

Consequently, if we look at Erving Goffman's (1974) *Frame Analysis*, we might be able to derive a much better understanding of "what is going on" when digital games are situated in an educational environment and of teachers' role in game-based learning.

In Goffman's book *Frame Analysis: An Essay on the Organization of Experience* (1974), he introduced a theoretical and methodical tool, the Frame Analysis, to understand our experiences in our daily life. Goffman argued that our experience is shaped by frames that determine how one structures our experiences and organize our activity. Concretely, Goffman's frame analysis helps participants to, simply put, understand "What is going on here?" in any particular situation. A frame is embedded in the social context, which shapes the frame by its rules, the norms, the possible roles, the expectations, etc., and is available to "... the social actors to make sense of any given situation or encounter" (Crawford 2009, p. 12). However, as Goffman argued, social encounters and interactions are clearly structured and work on the foundation of shared values, expected and accepted roles, patterns of behavior, and so forth. Social encounters and interactions are therefore somehow limited to the social context and its commonly shared and agreed values, so not anything is possible. This can be illustrated based on the example of a boxing and street fight. If one witnessed a street fight, you would ideally try to settle the fight, call for help such as the police or ambulance to prevent further escalations and injuries. Yet, if one witnessed the same encounter, but this time the participants are wearing gloves and the fight takes place in a boxing ring within a stadium, one would switch to the role as spectator, who cheers for every successful punch. Hence, the nature of activity is the same, i.e., fighting, though the social context shapes the frame, which in this case helps the social actor to make sense of the given situation and act/behave accordingly.

The boundaries that define each frame are described as "membrane" (Goffman 1961) and can be understood similar to the function of cell membrane, which is to protect the cell from its surroundings. Yet, contrary to a cell membrane, the frame membrane should not be understood as active agent that actively "protects" a frame. Thus, the frame membrane can be seen as filter to separate rules, norms, possible roles, expectations, etc., which reinforces the understanding of a particular situation, from factors that conflict with a frame in a given social contact and ultimately break a frame and cause confusion in the social actor. If we apply the concept of a frame membrane to our aforementioned illustration, concretely to a boxing fight, then factors such as a monumental stadium, an entertaining commentator, light shows, like-minded peers, etc. would reinforce the frame of being in a boxing sport event and acting as a spectator. Though, if, e.g., the boxers suddenly decided to sit down and to play a game of chess or if classical music would play constantly in the background, then this would disturb the frame and break the membrane, which would lead to confusion.

It is important to highlight that Goffman doesn't see frames as engineered or created by social actors, but "... rather as pre-existing schema which they simply employ" (Crawford 2009, p. 13). This limits Goffman's frame analysis to a certain extent, as it can be argued that frames are not just pre-existing schemas, but can be also engineered by social actors for social actors. For instance, if we look at games and game experience, it can be suggested that game developers and game designer are playful frame engineers of their game. Hence, during gameplay players take over game-generated and designed roles in a designed context with its designed rules, behavior pattern, and expectations.

When people are engaged in games, they take over a playful frame and mind-set; hence, games play very well together with the membrane of such a frame as they promote a playful attitude and do not break the membrane. Well-designed games are therefore a very strong catalyst for a playful state, frame, and mind-set. However, if we look at games in an educational setting, we can derive certain problematic as it leads to an unavoidable clash of several frames (Fig. 28.1) and to factors that often break the membrane of a playful frame. The social context, its rules, norms, expected behavior, and roles of a school and classroom environment differ often very much to the ones of a game world. This also accounts for the role of the teacher and the one of a student within an educational environment. If the role within a game world and the role as a student and teacher are not coherent and there is no transition

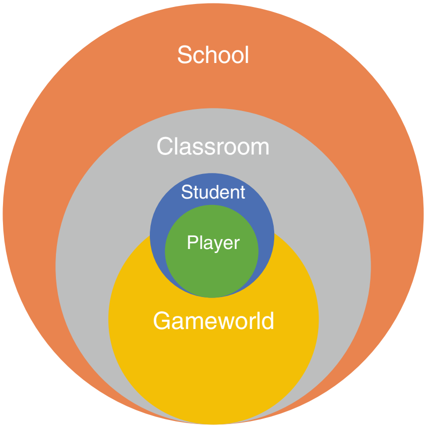


**Fig. 28.1** Clash of frames – Each circle represents a frame that is embedded in a different social context, which shapes the frame by its rules, the norms, the possible roles, the expectations, and so forth. Hence, if the school and classroom environment does not interact coherently with the frame of a game world/player, then the usage of games for learning might not produce the desired effect and lead to several practical complications

between the game world and the classroom, then it can be argued that the usage of games for learning will not produce the desired effect and lead to several practical complications. The frame of a school and classroom environment is shaped by their social contexts, which expect different rules, norms, possible roles, and expectations from teachers and students than from, e.g., the social context and frame of a game world. Hence, using games in an educational environment, which often does not interact well with the membrane of a playful frame, will inevitably lead to a break of the membrane and can break a student's playful frame when engaged in a digital game.

Therefore, similar to a game designer, who is in a sense an engineer of playful frames, it can be proposed that a new meaning for the role of the teacher in game-based learning could be an engineer of playful frames that extends the game world to the classroom in order to create a playful knowledge loop between the game and the curriculum. Games should not only be seen as tool to support teacher's teaching but also empower teacher's professional identity as active and self-creating subjects (Lasky 2005). Therefore, extending the game world to the classroom means also to enable an active role of the teacher within the game world, e.g., as co-participant or game master. In addition, it can be proposed that games for educational purposes will have a better effect, when the game world and the classroom environment interact with each other coherently.

Ultimately, Goffman's frame analysis helps to underline and illustrate the complexity and implications when digital games are situated in an educational context, or any other context. Especially in an educational context, many variables need to be addressed and considered before using digital games for learning. Each variable within an educational context, e.g., the curriculum, classroom environment, technical infrastructure, teacher's and student's role in game-based learning, teacher's game literacy, and so forth, needs to be meaningfully connected with the playful frame of a game world. If the digital game and the playful frame do not interact coherently with all factors and variables within an educational context, digital games for learning might not produce the desired value and practicality.

#### 28.3.1.1 Study I: "Teacher Roles in Learning Games – When Games Become Situated in Schools" (Magnussen 2007)

This section emphasis will be laid on how the game design addresses the role of the teacher, how the lack of sufficient game literacy led to confusion or problems when performing the intended roles, and how such confusion can be better understood when applying Goffman's frame analysis.

Magnussen (2007) investigated the different roles teachers perform while students and teachers played the game *Homicide*, which was developed by the Learning Lab Denmark. In Homicide students take over the role of forensic experts whose mission is to solve several murder cases.

The game is organized in different investigative groups, which work on their individual cases and share their findings and information about their case in group meetings. During the meetings, the teacher performs the role of chief of police to encourage students to set new goals. After each meeting, the teacher unlocks new parts of the game. The game takes place primarily in the classroom and not on the computer. The interface of Homicide acts as extended database, which gives the student access to various information such as videotaped suspect interviews, pictures, maps, and information about evidence. Hence, students have to use the information available in the database, to plan their investigative process and to any execute investigative analysis in the school laboratory. Based on their findings, the groups come up with theories, which are presented to other groups and which end the game.

Homicide is not a commercially available game and was particularly developed as learning game, rather than for a non-educational purpose. Homicide can be seen as a good example of addressing the role of the teacher in the game design of the game. The teacher's role in the game was as following addressed:

> In the manual the teacher's role is primarily defined as a helper and initiator. The teacher has access to all the answers and should advise students by asking open questions that will help players focus and get back on track if they get stuck in the investigation process. The pupils can get the data they need from the 'police database' but the teacher is still in control of what is released at what point in the game. In the manual, the teacher is also encouraged to role-play the chief of investigation who advice the investigators, but let them take the decisions. The chief sets the agenda at the status meetings where all the groups reports to each other and he or she asks critical questions about the further investigation. The teachers should work on striking a balance where they play roles to a degree that feels natural to them instead of not playing roles at all. In the manual, the teachers are reminded that it can be disrupting for the pupils' identification with their roles in the game if they have to step out of the role in the game and into the 'pupils' role whenever they speak to the teacher. In the manual it is stressed that it is important to maintain the illusion throughout the game that the pupils are doing something important in solving the cases, this keeps up motivation for conducting the investigation process.

Hence, educators were intended to perform the role of a game master, who mediates the game, provides in-game support and guidance, and acts as collaborator. Albeit the teacher's was addressed in the game design and communicated to the educator through a manual, the implementation for the teachers was not as straightforward as the developers might have participated. Concretely, the developers and the author of this study received several comments from teachers that they need an overview of the game mechanics and game play itself, which the manual did not provide (Magnussen 2007). Thus, it was necessary to provide several 3-h introduction and training sessions in order to give a good overview of the role of the teacher within the game, the game itself, and the technical aspect (Magnussen 2007). Even though the role of the teacher was acknowledged and addressed in the game design, the actual implementation would have not been successful without providing introduction and training sessions by the author of the study. Therefore, it can be argued that the role of the teacher should not only be included in the game design but also in the game development process as participatory designers in order to design game-based learning application for the actual stakeholders, i.e., teachers. Moreover, this case illustrates very well how teachers need to adapt to the game instead of the other way around, which, again, brings forth one of the dominant obstacles teachers face when implementing games into their teaching: time and lack of sufficient knowledge.

Furthermore, one particular aspect of the above described agenda and role of the teacher in the game should be highlighted, that is, the importance of keeping up the illusion that the students play a game and that their roles within this game context are of importance. Magnussen observed one situation where the teacher fails to keep up this illusion and undermines the game on several levels (Magnussen 2007).

> In the specific situation, members of two groups were standing and sitting around a table in the common area where the workstations were. Two members – a girl and a boy – from different groups were using a brush to apply powder to the objects they had received from the teacher. There were a lot of children from the different groups around the table. These were the first two groups who were lifting fingerprints and members from all groups were interested in how it is done. The girl (girl1) had just finished brushing a hammer that she believed was the murder weapon. The fingerprints she was supposed to lift was not clear. In this example she was asking the teacher Thomas to take a look at the hammer she was testing for fingerprints. Thomas came over and stood beside her while they talked.

**Girl 1**: Thomas could you come over here, please?
**Thomas**: Yes
**Girl 1**: I don't think this is clear. I can't even see it.
**Girl 1**: You can see theirs' (their fingerprints) (points to the CD the other boy at the table is testing for fingerprints)
**Thomas**: Try this instead, I know that . . . (low-voiced, inaudible)
**Girl 1**: That's not ours
**Thomas**: No, I know. It's some extra things I have if it didn't work. Girl 1 uncomprehending takes the plastic bag he gives her.
Another girl (Girl 2) has been following the conversation between Thomas and Girl 1.
**Girl 2** to **Thomas**: But what will that help?
**Thomas**: The point here is that you must practice lifting fingerprints off objects.
**Girl 1**: Should I just try here again? (she points to the hammer.)

**Thomas**: Yes, try again, but if you don't find anything, then try those (point to the objects he has just given her).
**Girl 1**: Yes, then I'll try those.
**Thomas**: Try and look at those too. (The objects he has given her.)
**Girl 1**: But this is not some of the things we get?

After this conversation, the girl (Girl 1) kept brushing the hammer, but ultimately tried her luck with one of the objects (a black disc) the teacher had given her. The main purpose of giving the black disc to the student was to practice the skill of lifting off fingerprints; however, since the disc itself was not part of the game, the girl ended about being confused how and if the fingerprints on the black disc are related to the game (Magnussen 2007).

Magnussen argued that this confusion would have not occurred if the teacher told the student to practice this skill in a non-game-based context, or in a non-playful frame. Moreover, the author used the concept of the magic circle of play and breaking the rules of the game as explanation for this confusion (Magnussen 2007). However, Goffman's frame analysis might be a more suitable tool to analyze this situation and to explain the student's confusion. When the girl tried to investigate the hammer and lift off the fingerprints to collect valuable evidence, she was seeing the situation through the frame of a professional police investigator; moreover, the frame of a professional investigator was embedded in the playful frame of a game. Therefore, when the teacher advised her to practice her skill with a black disc, which was not related to the game, the membrane of the playful frame as a professional police investigator broke and resulted in confusion. Thus, in this case keeping up the illusion of playing a game and having an important role in this game world failed because the teacher introduced an activity that was not compatible with the playful frame of a professional police investigator. Additionally, the item the teacher introduced was also not compatible with the playful frame of the game as it was unrelated to the game world.

This particular situation yields the fine balance, when games and roles are situated in an educational environment, between keeping the illusion of a game and of breaking the game frame at all. The teacher definitely wanted to help the kids in achieving their goal, though seemingly unimportant actions or items can lead to confusion and disengagement.

Consequently, situating digital games in an educational environment introduces various challenges. For example, in this study the teacher was not aware of how to meaningfully embed his practice advice in the game world, how to build a connection between the game and his advice, and how this might affect students' engagement with the game. Homicide is a good example of how to implement teachers' role in the game design. However, it can be proposed that this is not enough, as teachers also need to be able to adjust the game in such situations, which means that teachers need sufficient knowledge not only about game literacy but also about game design. Moreover, without the introduction and training sessions, the teachers would have had troubles to fully understand the role and the game, which suggests that when games for learning are designed, it is pivotal to integrate teachers as participatory designers as well.

#### 28.3.1.2 Study II: "Teachers' Many Roles in Game-Based Learning Projects" (Berg Marklund and Alklind Taylor 2015)

In this section emphasis lies on the technical barriers and the time that is required for planning and organizing prior to the actual integration of the game in the classroom. Additionally, how seemingly small details within a game world can lead to disconnect and the many roles teachers need to perform during and to prepare for game-based learning sessions.

Berg Marklund and Alklind Taylor (2015) examined the different roles teachers need to perform when integrating digital games in their educational environment. Specifically, the authors introduced *Minecraft Edu,* which is an adapted version for educational purposes of the commercial pendant *Minecraft*, to integrating it as classroom activity. It is important to highlight that Minecraft's game design and core structure do not address the teachers' role, unlike, for instance, Homicide. Therefore, it does not create a meaning of the teachers' role within the game context. Thus, this study addresses very well the different roles teachers need to abstract and the challenges that come along when situating a digital game within an educational environment. We can divide the roles into two categories: firstly, the roles the teacher has to take on before the actual game session and, secondly, the actual roles teachers perform during the game sessions. Prior to roles during the classroom sessions, teachers need to take on the roles as technical administrator and game administrator, which involved tasks such as designing the game-based curriculum, establishing the infrastructure to enable gaming sessions and administrating tasks during and around gaming sessions (Berg Marklund and Alklind Taylor 2015).

Berg Marklund and Alklind Taylor argued that one dominant obstacle, for the integration of digital games in an educational environment, is the fact that digital games are just extremely "... laborious and resource intensive to use, and that there are few standards established to guide educators through the complex process of integrating games into their working environments" (Berg Marklund and Alklind Taylor 2015, p. 359). This becomes even more evident when we look at Table 28.1, which illustrates the necessary steps to integrate the game in an educational environment.

Moreover, the teachers involved and the researcher had to, prior to the actual implementation, plan, design, and adjust the curriculum to the game. Additionally, the process of the game integration heavily relied on the researchers, as the teachers admittedly lacked of sufficient game literacy, as illustrated below:

> When it came to integrating the game into the classrooms, the primary concerns for both cases were: the uncertainty of hardware reliability; the teachers' self-admitted low gaming- and technology literacy; and the limited amount of working hours they could feasibly spend on preparing for classroom gaming sessions. In the cases studied, the low game- and technology literacy of the teachers would make it highly unfeasible to start any type of game-based learning if it were not for a couple of ameliorating circumstances: the presence of the researcher, and the teachers' students themselves as both classes had several students who were very proficient with both computers and the used game. The process of game

**Table 28.1** Overview of the necessary steps to integrate a digital game into an educational context

| | Activities | 7th grade classroom | 5th grade classroom |
|---|---|---|---|
| Inventory | Take inventory of available hardware/resources | | X |
| | Evaluate student profiles | | X |
| | Examine curriculum goals | X | X |
| | Examine game software | X | X |
| | Establish educational goals to be served by the GBL project | X | X |
| | Pull in organizational support structures | X | X |
| Implementation | Prepare hardware | | X |
| | Purchase game licenses | X | X |
| | Installation of software | X | X |
| | Prepare the classroom environment | | X |
| | Prepare the game environments | | X |
| Maintenance | Maintenance | X | X |
| | Setting up servers | | X |
| | Preparing in-game examples | X | |
| | Saving games and handling backups | | X |
| | Tech support during game sessions | X | X |
| | Closing down lessons | | X |
| | Hardware maintenance | | X |
| | Patching and software maintenance | X | X |

Note: Retrieved from Berg Marklund and Alklind Taylor (2015). Teachers' Many Roles in Game-Based Learning Projects, p. 363

> integration thus relied primarily on the researcher, and when the researcher was not present the teachers could get some assistance from the more technology proficient students in the classes. – (Berg Marklund and Alklind Taylor 2015, p. 362)

This statement underlines once more the great obstacles teachers face when trying to integrate digital games into their teaching and also supports the evidence found in the listed studies earlier in this book chapter. It can be argued that this is a very strong indicator that currently used games for learning are simply not sufficiently designed for an educational environment, which means that factors such as the classroom, teachers' game literacy, available infrastructure, available time, and so forth are marginalized in the design of digital games for learning. However, this is also the case as many popular digital games for learning, such as Minecraft Edu, are based on the game design of commercial games, which ultimately do not take such elements into consideration.

Once the sessions had started, the authors observed several roles the teachers had to perform during the gameplay:

*The teacher as gaming tutor*, who guides and supports students' gaming experience, similar to a game master.

*The teacher as authority and enforcer of educational modes of play,* who guide students with an advanced level of game literacy and gaming experience, toward "... productive collaborations with their classmates" (Berg Marklund and Alklind Taylor 2015, p. 364). This is of importance as previous studies (Frank 2011) have shown that students, who are more proficient players, tend to shift their focus toward mastery of the game goals and game mechanics, instead of engaging with the subject matter objectives.

*The teacher as subject matter anchor*, who tries to connect the game world to the subject matter objectives, or creating a knowledge loop between the digital game word and the real-world learning environment.

The role as subject matter anchor will be now particularly reviewed, as the authors of this study observed one of a commonly occurring challenge when digital games are situated in an educational environment. Precisely, for this reason, teachers often have difficulties to bridge the game content with the actual subject matter objectives in the curriculum (Berg Marklund and Alklind Taylor 2015), or creating a knowledge loop between real-world and digital game world learning environments. Ergo, if the game is not specifically designed to teach objectives that match the curriculum with "... high level of authenticity and fidelity, the task falls on the teacher to draw connections between the game content and the subject matter" (Berg Marklund and Alklind Taylor 2015, p. 365).

This becomes even more challenging when the game content does not entirely fit with the subject matter as the transcript illustrated in Fig. 28.2.

[Julie and Louise, two inexperienced players, are building part of a monastery, they want a bookshelf in their building (it's a building where they would be thematically appropriate), so they place one down, a brief silence follows, and the following exchange takes place]
Louise: A little bit too colourful, right?
[...]
Julie: Let's remove them.
Louise: Yeah.
*They go quiet, mouse clicks are heard, the teacher comes up to the group*
Teacher: Why did you remove them?
Louise: It looked a bit weird.
Julie: Yes.
Teacher: A little bit too modern?
Julie and Louise: Yeah.
Teacher: Well, there are modern-looking book spines in there, but you can try to imagine that they're the type of books they would have back then.

**Fig. 28.2** Excerpt from fifth-grade classroom transcript, which illustrates clashes between game content and subject matter (Retrieved from Berg Marklund and Alklind Taylor (2015). Teachers' Many Roles in Game-Based Learning Projects, p. 365)

In the above example, the visual game content clashed with the subject matter (medieval history). Compared to the role of teacher in study 1, the teacher here was not instructed to maintain the illusion of the game world throughout the entire session. Moreover, if we look at this example using Goffman's frame analysis, we can derive a better understanding of the problematic in this situation. This time it was the game content that triggered a disconnect or a break in the frame membrane of the students. Minecraft Edu was used for medieval history, ergo, the subject matter objectives and the frame the students took over was aligned toward medieval times. What happened here was that the game world of Minecraft Edu was embedded in a medieval frame, yet the subject matter objectives and the game content were not completely coherent. In this situation the students experienced a disconnection between the real-world and the digital game world learning environment. Moreover, such seemingly small details can cause students having troubles "...seeing past small disconnects between game content and the subject matter" (Berg Marklund and Alklind Taylor 2015, p. 365). As earlier mentioned, the teacher was neither instructed nor informed to maintain the illusion or how to best connect the game content with its real-world counterpart. In this situation the teacher advised the students that they should try to pretend that this modern-looking counterpart represents a medieval bookshelf. This example illustrates once again the fine balance between real-world and a digital game world learning environment, the complexity of situating digital games in an educational environment, and how easily a playful frame can be broken and lead to disconnect or confusion.

For these abovementioned reasons, it can be argued that besides integrating teachers as participatory designer in game-based learning applications, it is also essential to provide training and constructions on how to connect and combine the real-world and digital game world learning environment. Consequently, it can be suggested that it is pivotal to equip and provide training for educators in game literacy and game design for educational purposes in order to enable teacher to integrate games into their teaching more effectively.

Before we look at the third study, teacher agency and the sense of professional development will be introduced in order to illuminate how new school reforms and tools affect teacher's identity and sense of professional identity.

### *28.3.2 Teacher Agency and the Sense of Professional Development*

Sue Lasky (2005) argued that little is known about how new school reforms and policies, which also introduce new tools, affect teacher's identity and experience. Moreover, it was stated that teacher's professional identity was often challenged by and was in conflict with new introduced policies that were accompanied with a new curriculum or assessment techniques (Lasky 2005; Vähäsantanen 2013). The introduction of new policies and tools was often followed by new identities that were in conflict with teacher's existing identity. Additionally, new tools, curriculum, and new classroom assessments often challenged and got in conflict with teacher's belief about how to teach (Lasky 2005).

A post-structural approach to agency will help us to underline the importance of teacher agency, identity, and relationship to their students, which sees the teacher as "... active and self-creating within processes of becoming, acting in work practices and interacting with other actors, despite being bound up with especially power relations and discursive practices" (Vähäsantanen et al. 2009, p. 4). Therefore, it is vital to involve and address teachers in school reforms and the implementation of new policies, to foster teacher's identity and to not constrain teacher agency as active subjects within new reform contexts. Teachers who experienced a conflict between their existing and suggested identity in a reform context felt that their professional identity was threatened (Vähäsantanen 2013). Thus, they were not able to influence the situation, because they were not able to actively negotiate the context of their work. Another important aspect is the nature of interaction between teachers and students, which can be constrained and hindered by new reforms and tools (Lasky 2005). According to Lasky (2005), the teachers' sense of purpose and identity, besides teaching the curriculum and academic skills, was greatly informed by their ability to connect with their students and by being an integral part of their student's safety net of support. Moreover, teachers reported that their job satisfaction greatly derives from "... their interaction with students and the feeling that they had some kind of positive influence on student's academic, social and emotional development" (Lasky 2005, p. 906). Furthermore, students showed more interest in the subject being taught when the teacher was able to connect with their students. Also, being able to establish a trusting and respectful relationship with their students was suggested as a crucial factor for learning to occur (Lasky 2005). Yet, teachers often struggled to maintain such a relationship, as new policies and tools constrained teacher's identity and sense of purpose (Lasky 2005).

Arguably, digital games for learning and teaching can be an opportunity to empower a teacher's existing professional identity, so they become comfortable with and gain ownership over game-based learning. Moreover, it is pivotal to foster teacher's existing sense of purpose, agency, and professional identity in a digital age, by facilitating spaces and tools that allow teachers to be an active and self-creating subject within novel contexts. Lastly, it can be suggested that game-based learning should not only empower teacher's existing professional identity but also foster the relationship with their students in a digital age, entailing joint meaning making and knowledge construction between educators and learners.

#### 28.3.2.1 Study III: "Facilitating Dialog in the Game-Based Learning Classroom: Teacher Challenges Reconstructing Professional Identity" (Chee et al. 2014)

In this section emphasis is laid on the challenges teachers face when trying to facilitate student dialogue and how teacher's professional identity was challenged when implementing game-based learning into their teaching and how they dealt with (re)constructing their teacher identity (Chee et al. 2014).

Hence, Chee et al. (2014) investigated teacher's capacity to establish game-based learning dialogic facilitation with their students, using the mobile game *Statecraft X* in conjunction with the Statecraft X curriculum. The curriculum, which addresses the topic "principle of governance," is based on the game Statecraft X and targeted for social studies taken by 15-year-olds.

Chee et al. argued that in previous studies teachers had reported that they had difficulties learning how to facilitate student dialogue when applying game-based learning, without any support from their school leadership, professional training, or preparations (Chee et al. 2014). In this study, teachers had the support from their school's leadership in addition to several professional development workshops, which introduced them to the concept of dialogic facilitation with game-based learning. Yet, Chee et al. clearly argued that:

> Like learning to swim, enacting an unfamiliar pedagogical role in the classroom constitutes a performance of teaching. The challenge is not about knowing what to do but being actually able to do it . . . Thus, learning some subject domain, Y, is not equivalent to learning about Y (just as learning swimming is not equivalent to learning about swimming). Consequently, no amount of lecturing, questioning, discussion, or self-study can adequately prepare a teacher for enacting game-based dialogic facilitation in front of, and with, students. A teacher's capacity develops with practice over time. Representational modes of learning, based predominantly on language, lead to passive and inert outcomes. They cannot deliver what teachers need: the capacity for enactive performance. (Chee et al. 2014, p. 304)

This illustrates well that time is one of the biggest issues when teachers try to integrate digital games into their teaching, which underlines the reality of the practicality of game-based learning. Thus, even if teachers are prepared, prior to the actual implementation of games into their teaching, with workshops and professional developments, so they develop game literacy and an understanding of the concept behind game-based learning, it is no guarantee that they will ultimately be able to actually use game-based learning effectively without sufficient practice. Additionally, similar to previous studies, teachers often do not have such support, such as researchers who introduce teachers to the digital game and how to best introduce the game into the classroom and teaching.

Another big issue, which teachers face in the game-based learning context, is the fear of not knowing and the feeling of "letting their students down," because ". . . they are unable to rise quickly to the standard of professional performance needed" (Chee et al. 2014, p. 307). This is because digital games for learning come along with a variety of new teaching practices and demand from teachers to "think on their feet" at all the time (Chee et al. 2014). In this study some teachers expressed that they felt overwhelmed when they suddenly need to prepare, besides the projector screen and the whiteboard in a linear fashion, also several additional materials related to the digital game (Chee et al. 2014). Hence, the digital game Statecraft X in conjunction with the Statecraft X curriculum challenged teacher's existing identity and their way of preparing the lesson and how to teach. This becomes even more evident when we look at particular teacher statement, who had to overcome old/existing teaching habits.

The above excerpt underlines how new tools in addition with a new curriculum can or often challenge and get in conflict with teacher's beliefs on how to teach or teaching habits.

> When asked about the challenges she faced enacting the Statecraft X curriculum, Adele spoke of the difficulty "of really being a facilitator rather than the traditional 'imparting of knowledge'" that she was accustomed to. She added, "I think I am still used to the habit of talking and talking and talking and talking. Yeah." In a more reflective moment, Pauline also shared:
>
> **And in fact sometimes because you are so used to doing things a certain way, and then you are very comfortable yet you are confident in that … it is what you are good at but because of that, it hinders you and then you have certain blind spots.**
>
> Later, Pauline added:
>
> **Yeah we are always prepared with PowerPoint slides and we are … And even if there is a discussion we know where to always go back to. And I think being used to that. That is a hindrance that I need to get rid of.** (Chee et al. 2014, p. 308)

As earlier mentioned, teachers are often confronted with the fear of now knowing when integrating digital games in their teaching. Teachers fear that students would know more about the digital game used or game literacy in general, which would challenge their position as teacher who possesses subject knowledge and undermines their position in the classroom as knowledge authority. The example of a teacher below shows a positive response to this, when the power relation between the teacher and student was challenged, as she was willing to bring herself down to the same level of the students and become a facilitator.

> …. initially as I you know, started as a fresh beginning teacher, it's really like okay, a teacher um doing the teaching. And um … it's more of top down because I'm the one having all the subject knowledge content. I have all the information and I know that … I clearly know that my students do not have access to all these. So I feel that I have an advantage over my students …. So I feel I have the upper hand. But you know as I do this um Statecraft X project, I find that it is … Okay, I [laughingly with emphasis:] descend to be of the same level as the student whereby I find myself learning a lot from the students and they are definitely in the capacity to teach me. And in fact, some of them they might even know more than me. And from a teacher, I become a facilitator. And at the same time, I am also a learner. So I'm of the same level as the students … (Chee et al. 2014, p. 310)

The same teacher also stated that it was very important for her to build a rapport and good relationship with their students, which supports Lasky's (2005) findings, which suggested that teachers found it crucial to build a healthy relationship with their students for learning to occur. However, it is of importance to note that many teachers have struggles to "let go" of having the upper hand due to their content knowledge, as Chee stated that teachers who "feel that their professional identity demands the maintenance of high power distance, especially in Asian cultures, wrestle with the dilemma of striking a practical balance between school norms and pedagogical requirements" (Chee et al. 2014, p. 311).

Introducing digital games in conjunction with a new curriculum into teaching often challenges teacher's professional identity and existing relationships and roles in the classroom. This is very important to understand in order to develop a holistic view on game-based learning and the complexity of the many contexts and variables involved and affected. Though, as Chee also suggested, digital games like Statecraft X are an opportunity to redefine teacher's relationship with their students. It is also an opportunity to reduce the teacher-student power gap in order to open up dialogue and to give students an active voice within the classroom, so that "*...productive learning can take place*" (Chee et al. 2014, p. 311).

## 28.4 Discussion

### *28.4.1 A Culture of Participation – The Teacher as Designer of Playful Frames*

Instead of focusing on how to develop educational games for the classroom, I suggest we should focus on how we can facilitate a teacher culture of participation (Fischer 2014), in which "...not every participant must contribute, but all participants must have opportunities to contribute when they want to" (Fischer 2014, p. 201). In this sense, a culture of participation moves toward actors who actively contribute as designer in personal meaningful activities, instead of just passively consuming (Fischer 2002). Consequently, we should strive toward equipping teachers with (game) design thinking and models, knowledge, and skills that enable teachers to become active agents within novel contexts, such as game-based learning and engineers of playful frames. Therefore, the anticipated development of a participatory design model, similar to the approach of "Edukata" by Toikkanen et al. (2015) who developed a participatory design model with teachers for creating learning activities in ICT school, envisages to create *templates*, which extend the game world of existing game-based learning applications to the classroom, and *playful tools*. Such a template envisages creating a playful knowledge loop between the real-world and the digital game world learning environment, which means expanding the game world to and blend it with the classroom. This will give teachers the opportunity to be a self-creating and an active agent in the context of game-based learning and would allow teachers to develop personal comfort with and ownership over game-based learning applications. The playful tools aim to be teacher-created tools, in digital or non-digital form, such as a set of cards, board games, playful design challenges that turn the classroom into a game, etc., to foster design thinking, creativity, playfulness, and twenty-first-century skills in the classroom.

That is to say that instead of designing another digital game for learning/teaching, we should see digital technology and games as an opportunity to empower teachers and to create new meanings of the role of the teacher in a digital age. Thus, the teacher is someone who is able to design learning environments that respond to students' holistic learning lives (Kumpulainen and Sefton-Green 2014) and creates situations where creativity, playful learning, and knowledge co-creation can flourish. Therefore, this participatory design model envisages empowering educators through resources that facilitate playful and game design thinking. Firstly, so they develop personal comfort with and ownership over game-based learning. Secondly, so they are able to create (playful and gameful) design challenges and solutions, which they can integrate into their teaching.

### *28.4.2 Game Design Thinking and Game Literacy as Part of Teacher Education*

It will be pivotal to make courses on game design, game literacy, and the usage of digital games in an educational context, part of teacher education and professional development. However, it is important to underline that these courses should be only optional for teachers who are interested in the usage of digital games for learning. This is important as it should be argued that digital games are just one of many tools that can enhance teaching and should not be seen as the one and only tool to enhance teaching and learning. Digital games for learning are, as so many other tools, an opportunity to enhance teaching, though educators, without sufficient knowledge and training, will and have difficulties (Chee et al. 2014; Magnussen 2007; Björn Marklund 2014; Shah and Foster 2015) integrating digital games in their teaching and the classroom. As Chee (2014) argued, it won't be enough to just know about digital games and prepare teachers through short lectures, workshops, or discussions for the usage of digital games in their classroom. Similar to any sport, where it is a big difference if you learn a sport or if you learn *about* a particular sport, it will require a lot of practice and training to enable game-based learning effectively.

Thus, all three empirical studies underlined that without previous instructions and the presence of the researchers, teachers would have had difficulties to integrate the game into their teaching. Moreover, every student plays differently and has a different approach to playing, and even some students have never played a digital game at all. Consequently, teachers need to be adequately trained and prepared to manage the various ad hoc situations that emerge during game-based learning and need to be able to create a connection between the digital game world and the subject matter.

Ultimately, it should be argued that in order to harness the full potential of digital games for teaching and learning, it will be crucial to give teachers the opportunity to receive sufficient support by their school, through professional long-term training and by offering courses on game design and the usage of digital games for teaching in teacher education.

## 28.5 Conclusion

This chapter provides an overview of the role of the teacher in game-based learning and a summary of the most dominant obstacles teachers face when trying to integrate digital games for learning into their teaching, by examining the importance of the teacher for learning to occur, by looking at various studies to derive the main barriers teachers face when integrating digital games into their teaching, and by using three empirical studies to address and to emphasize the most dominant challenges and current roles teachers perform during game-based learning. For the empirical studies, the chapter drew on Goffman's frame analysis and how new policies and tools can affect teacher agency and the sense of professional identity, to illustrate various implications and the complexity when digital games are situated in an educational context.

This research argues that the crucial role of the teachers has been widely neglected or marginalized in the game-based learning discussion. Research on the role of the teacher in game-based learning is still in its infancy, and it lacks of empirical studies that address the role of the teacher and the practicalities when situating digital games in an educational environment. Moreover, the role of the teacher has been also widely neglected in the game design for digital games for learning, be it as co-developer/designer in the design process of game-based learning applications or as active role in a digital game for the classroom. The chapter contends that instead of seeing the role of game-based learning to motivate and engage students, games should also be viewed as an opportunity to teacher learning and empowerment, giving teachers a sense of ownership of teaching and learning. This chapter proposed a participatory design model for teachers in order to move toward a culture of participation and, therefore, empower teacher to become active agents within novel context and engineers of playful frames. This chapter proposed one possible meaning of the role of the teacher in a digital age as meta/game designer of their own classroom.

Lastly, it will be necessary to offer sufficient support for teachers who are interested in the usage of digital games for learning, by providing long-term professional training and by providing courses on game design (thinking) and game literacy in teacher education.

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# Chapter 29
# Building Context-Aware Gamified Apps by Using Ontologies as Unified Representation and Reasoning-Based Models

**Maha Khemaja and Félix Buendia**

**Abstract** Mobile serious games (MSGs) or gamified apps are kind of user-centered applications where fun and serious aspects are combined in order to enhance users' experiences. Typically, apps are developed to target a specific purpose for also a specific audience. However, in real settings, a given app could have different users with different characteristics, preferences, contexts, and goals related to gamification. Besides, context awareness is the capacity of a system to take into account the user's context and adapt its behavior accordingly to that context. This chapter proposes a generic framework that helps developers to build context-aware MSG or gamified apps. This framework relies on a unified representation of gamification expertise and context by making use of ontologies and micro-services. As a proof of concept, the framework is used to design a context-aware gamified app prototype for promoting campus facilities.

**Keywords** Gamification • Context awareness • Ontologies • Reasoning • Micro-Services

## 29.1 Introduction

Context awareness is increasingly being applied to user-centered applications (Schilit and Theimer 1994; Schilit et al. 1994; Mowafi and Zhang 2007). It is the capacity of a system to take into account the user's context and adapt its behavior (functions, services, human-computer interfaces (HCI), etc.) accordingly to that context (Dey and Abowd 2000). With this aim, the system has: (1) to manage a set of representations about the user's context and experiences, the system domain

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or subject, as well as the system's own structure, organization, and behavior and (2) to use relevant adaptation and/or reconfiguration mechanisms in order to respond efficiently to user's changing context.

Mobile serious games (MSGs) or gamified apps pertain to a category of user-centered applications where fun and serious aspects have to be accurately designed and relevantly combined in order to enhance users' experiences (Černezel and Heričko 2013; Asuncion et al. 2011). For instance, MSGs are considered as games that promote serious objectives such as education, training, and information using entertainment principles, creativity, and technology. They also stimulate active users' involvement through exploration, experimentation, competition, and cooperation.

Conversely, gamified apps are not recognized as full-fledged games (Deterding et al. 2011). They are apps to which game design techniques and mechanics have been applied to solve problems and engage audiences. Gamification also strives to encourage users to engage in desired behaviors in connection with the applications. Gamification can be leveraged by companies or by educational entities, respectively, as sophisticated marketing or active pedagogical techniques wherein users are engaged in games, while simultaneously being exposed to the ultimate objective of the entity.

Typically, SG or gamified applications implement a set of activities that are designed and developed to target a specific purpose for also a specific audience. It is the case, for example, of an e-commerce app or an e-learning platform where purchasing or learning activities are rewarded with points and badges and where loyalty (respectively, progress and success) is encouraged through gamification or SG. But in real settings, a given app (mobile app, Web-oriented app, etc.) could have different audiences where users could have different traits and characteristics. They could have different preferences and seek for different goals related to gamification or also enjoy differently gamification aspects, and, finally, they could use the given app when they span different contexts (at home, at work, on the move, alone or in-group, etc.). Taking the same example of the e-commerce Web site, some users may want to exchange rewards with proposed stuff, while others may prefer to have distinguished social status.

Therefore, building SG or gamified apps that take into account the user's context and adapt its gamification purpose, behavior, rules, game mechanics, and fun accordingly to that context, especially, when this latter is continuously changing is increasingly required. However, underlying development frameworks or gamification platforms such as UserInfuser, Badgeville, and Google Play Games Services (Herzig et al. 2012) do not provide designers and developers with enough assistance and flexibility to build such context-aware SG or gamified apps (Zichermann and Cunningham 2011). Furthermore, existent works have not proposed any relevant approach, based on best practices and expertise, to help developers or designers to integrate gamification or to adapt SG.

In the present chapter, context awareness and gamification mechanisms are considered as first-class reusable candidates that may be used for building or adapting different apps. As such, a generic framework for building context-aware

SG or gamified apps is proposed. This framework relies on a unified representation and specification for (1) user's context and experiences; (2) gamification goals and rules; (3) gamification's good practices and design patterns; (4) system's domain or subjects; (5) system's own structure, organization, and behavior; and (6) relevant adaptation mechanisms in order to respond efficiently to user's changing context.

The use of ontologies seems promising for addressing this kind of unified representation as it also enables applying reasoning techniques over those representations either for modeling gamification's good practices or rules for adaptation mechanisms.

Indeed, an ontology is considered as a body of formally represented knowledge based on a conceptualization (i.e., an abstract, simplified view of the world) composed by the objects, concepts, and other entities that are presumed to exist in some area of interest and the relationships that hold them (Genesereth and Nilsson 1987). Hence, ontologies have been exploited in many domains, thanks to their capacity to promote sharing of knowledge bases, knowledge organization, and interoperability among systems.

Formal ontologies are viewed as designed artifacts, formulated for specific purposes, and evaluated against objective design criteria. The research methodology applied in this context is design science based where, in general, researchers iterate over two activities: designing an artifact that improves something for stakeholders and investigating the artifact in context (Wieringa 2014).

Therefore, main contributions of this work are the designed ontological models and the set of micro-services prototype that will be used to help for developing mobile context-aware and gamified apps. Experimentation of the proposed framework is done through a case study that shows how it is used to help in developing a mobile app intended to new comers or visitors to discover one's campus facilities, and conclusions are drawn for further enhancements.

The rest of the chapter is structured as follows: Sect. 29.2 introduces MSG and gamification background. It compares and draws conclusions about existing related works. In Sect. 29.3 a motivating scenario is presented and analyzed in order to precise main requirements that the proposal attempts to answer. Section 29.4 describes the main contribution of the present chapter. It therefore addresses the main design principle of the gamification framework, its components, objectives, and how it is used through concrete scenarios.

Section 29.5 constitutes a description of the proposal and its testing. It presents therefore a prototype and shows the framework's usability.

Section 29.6 draws some conclusions and outlines further works.

## 29.2 Background and Related Work

In this section, several research areas related to SG, gamification, and context awareness are investigated. Though apparently independent, these areas represent complementary points of view, each of which brings insights, ideas, hints, etc. for building a more complete picture. Therefore, works allowing to identify SG or gamified app characteristics, features, and concepts (Deterding et al. 2011) as well as those related to approaches, strategies, methodologies, and frameworks (either theoretical, conceptual, or technical) for defining or building gamified apps or SG are considered (Vermeulen et al. 2016; Ašeriškis and Damaševičius 2014; Arnab et al. 2015; Domínguez et al. 2013). Additionally, works having addressed context modeling and context awareness either for SG or gamification or for more generic purpose systems are studied (Qamar et al. 2014; Alamri et al. 2013; Hardy et al. 2011; Edoh-Alove et al. 2013; Reichle et al. 2008). Finally, semantic- or ontology-based frameworks or models developed specifically for SG models or gamification are discussed (Challco et al. 2014) and (Challco et al. 2015).

In Deterding et al. (2011), authors have surveyed and situated the current use of gamification. Emerging definitions and related concepts have been identified such as gamefulness, playfulness, game thinking, game mechanics, playful design, etc.

Comparison and characterization of those terms and phenomena are made from different points of view. Results show that gamification relates to games not to play, and it always focuses on design elements for rule-bound, goal-oriented play with little space for open, exploratory, and free-form play. Another important concern is the high level of subjectivity and contextuality in identifying whether an application is a full-fledged game or a gamified application. The paper also stressed the benefits related to the large deployment and use of gamified apps especially as new inquiry and data services for HCI and game studies.

In Ašeriškis and Damaševičius (2014), authors attempted to extract and model gamification patterns from a set of known gamified systems. The novelty of the proposal is that extracted gamification patterns are visually specified and simulated using the machinations modeling language. The work had also used the MDA (Mechanics, Dynamics and Aesthetics) framework to describe respectively particular components of the "game," run-time behavior of the mechanics acting on player interactions, and, finally, desirable emotional responses evoked in the player. The machination framework provides a specific language for gamification (Van Rozen and Dormans 2014). It uses the concept of sources, drains, pools, and traders. The logic behind the language is that the gameplay is determined by the flow of resources, and, therefore, main patterns were specified by making use of those concepts. Examples of patterns are "time limit," "dynamic limit," "drain pattern," "property and chance," and "solver."

In Domínguez et al. 2013; Arnab et al. 2015, authors have developed a framework for understanding serious gameplay. The approach exploited symbolic Machinima by tracking and recording users' actions in virtual environments. Data collection and its analysis aim to serve later for authoring alternative game scenarios. In the same work, a behavioral model of gameplay has been specified. However, authors claimed the need for a domain ontology underlying a game, to enable the construction of a user profile by making inferences over the user's actions when confronted with challenges and choices in a given scenario.

Authors in Qamar et al. (2014) present an e-therapy framework that collects live therapeutic context by analyzing body joint data in a noninvasive way. The system assumes that each patient is surrounded by a smart 3D space that identifies her context and tracks her gestures. A specific approach is provided to model and generate a set of high-level SG-based therapies by composing complex gesture models from different primitive gesture sequences. The system used Second Life and Map browsing-based SG environment for immersive experience.

In Alamri et al. (2013), authors provided a cloud-based pervasive SG framework to support obesity treatment. The framework aims to engage people for exercising by using SG (exergaming) while monitoring their bio-signals by making use of body sensor networks. It provides relevant games and e-health services accordingly to user's contexts encompassing mainly temporal, spatial, and bio-signal parameters.

In Hardy et al. (2011), authors aimed to add context awareness to SG for sport and health. They proposed a framework for social networks and Internet-based Web services for capturing spatial and temporal context as well as vital parameters of a user. Context is captured and deduced from both Body Sensor Networks and multimedia information contained in Internet services such as e-mails, calendars, etc. Thanks to the MVC (model view controller) pattern, raw contextual data is intercepted through controllers, aggregated, and stored for further use during e-health and SG selection process. This work is characterized by its high-level adaptation of the frameworks facilities; however, SGs are not adapted. Moreover, the number of used SG is very limited as these applications are not open and do not provide possible interactions via exposed interfaces.

Edoh-Alove et al. (2013) have combined geomatics and augmented reality to improve the immersive aspects of SG. For that aim a spatial context was developed and exploited with an SOA (service-oriented architecture)-based solution. Compared to other solutions, the authors' work addresses the lack of context models for SG on multiplayer environments. Specific context elements and concepts have been specified. Moreover, a specific query language is provided in order to retrieve contextual data for all mobile platforms connected to the system.

In Reichle et al. (2008), authors have addressed context management for pervasive systems. They attempted to support all requirements of such environments. For that aim they proposed a comprehensive and integrated approach for context modeling especially for supporting software development based on MDD (model-driven development) approach. The context model is ontology based and provides three abstraction layers (conceptual, exchange, and functional). It addresses specific requirements of pervasive systems as distribution, mobility, and heterogeneity; it also helps and facilitates the analysis and design of context-aware applications in an MDD software engineering process.

Issues addressed in Challco et al. (2014) and Challco et al. (2015) are how to introduce gamification to deal with the problem of learner engagement and motivation in collaborative learning scenarios. The authors have addressed those issues by developing an ontology that aims to gamify collaborative learning scenarios. Therefore, the gamification ontology has been integrated to a collaborative learning ontology previously developed. The gamification ontology main concepts are identified in psychological as well as the game theory domains, and they are strictly connected to collaborative scenarios.

As a conclusion, it is interesting to notice that, though the set of works described in this section is not exhaustive, it not only shows the relevance of those works but also advocates the novelty of the domain and its openness to many perspectives. It is also worth to highlight that except the work presented in Challco et al. (2014) and Challco et al. (2015), about gamification domain ontology construction and provision, and that of Ašeriškis and Damaševičius (2014) which have used design patterns and gamification vocabulary for simulating gamified scenarios, all the other works have been more concerned with either gamification theoretical frameworks or context awareness applied to SG. More specifically, these latter provide specific views of context (related to bio-signals, body gestures, or spatial context). Furthermore, these works aim to select and provide SG and services accordingly to the user's context. The SG adaptation and its components' reusability are not addressed. Finally, neither context nor gamification have been conceptualized and formalized by making use of modular ontologies. Moreover, ontology provided in Challco et al. (2015) targets collaborative learning scenarios which may hamper its further reusability and extensibility. Therefore, the framework developed and provided in the present work is different.

## 29.3 Motivating Scenario

### *29.3.1 Scenario Description*

"Web IT Co" is a software development company whose main software product line is Web-oriented and custom-made software for promoting tourism and cultural heritage.

"3 M" is a company that manages museums and historical sites. It organizes and provides guided visits and journeys to its clients. "3M" is one of the most important "Web IT Co" clients. Its Chief Information Officer Mr. Smith has started 6 months ago to analyze users' interactions with his Web application developed long time ago by "Web IT Co." All his analysis results show that users easily drop out; they do not keep engaged with the application even when there are new proposed guided tours or amazing visits with a good narrative story that is reported by a pleasant speaker. He thinks that something was going wrong. Urgently he engaged a working meeting with the "Web IT Co" development team to figure out the problem and try to find out a solution.

After many hours of brain storming, the idea around gamification of the Web application has emerged. Very happy for this finding, the "Web IT Co" development team has rapidly added some rewards and badges to the Web application. They also added survey forms to collect user's opinions about it. However, they reported on difficulties found while reengineering the application due to its monolithic architecture, the strong coupling between its components, and the significant amount of code to be updated.

Three months later, users' interaction analysis showed a little positive change on the users' engagement. Users who answered the survey complained about the lack of motivation behind the gamification aspect. Many of them have not appreciated the rewarding system and noticed the lack of challenges, while many others expressed their desire to have mobile access to the application.

### *29.3.2 Scenario Analysis and Challenging Requirements*

Firstly, even if gamification could be a relevant solution to engage people and to influence positively on their behavior, it seems that it was not correctly designed and integrated to the Web application. Secondly, it is clear that the working team has not aligned gamification to the company business goals and/or strategies, and those users' preferences, differences, and specificities have not been carefully considered. Thirdly, it is quite evident that the working team has not enough skills, experience, and expertise for dealing with gamification issues. Finally, the underlying technology used to build the application makes it difficult to be easily reengineered and adapted to the users' needs.

Therefore, the following requirements and challenging issues are inferred. They are classified into technical as well as pragmatic issues.

From a technical point of view, it is mandatory to enhance software development techniques and provide software developers with different kind of support that help them to:

(1) Carry out easier development tasks
(2) Achieve faster software delivery rates
(3) Increase teamwork autonomy and efficiency
(4) Have facilities to integrate gamification and context awareness into existing business software applications or other serious software and to keep track of users' interactions and achievements in order to valuate every user's action
(5) Have facilities to provide context awareness, adaptability, and personalization to the software end users
(6) Ensure end user's mobility and (technology) device independence

For that aim, the gamified app should be delivered to different kinds of devices and platforms without additional development effort.

Points (1) and (2) are best achieved by providing reusable software components related to gamification and context awareness. The better these components are designed, the easier would be their reusability for building context-aware gamified apps.

Point (3) is best achieved, thanks to a thorough decomposition of the app to be developed into separate presentation, business logic, and game logic layers where the design and development of each layer is performed by specialized teams of designers and developers and shared with business experts.

Point (4) is best addressed by using flexibility and interoperability standards such as those promoted by SOA, Web services, and Semantic Web standards (Laskey et al. 2009 and Fensel and Bussler 2002). These latter are specifically needed to overcome heterogeneity issues of data and terminology due to the integration of different domains such as gamification, context awareness, and business domains.

To overcome the point (5) issues, relevant software infrastructure (i.e., Middleware, Technical Frameworks, etc.) that grants run-time auto-adaptability, reconfiguration, and personalization of the developed apps has to be deployed. Moreover, context awareness requires sound reasoning over the software architecture and its components. The underlying software infrastructure could be therefore extended with semantics and reasoning facilities to help developers achieve that aim.

Finally, the point (6) issue is best achieved by the use of relevant technical frameworks allowing cross platform development.

From a pragmatic point of view, gamifying serious applications by just adding game mechanics on top of business processes or interactions could not lead to a desired user's behavior. Worst, it could lead exactly to the reverse of what was expected.

Designing a good interplay between core business activities, game mechanics, and context requires the use of knowledge related to good practices, strategies, as well as relevant design patterns in order to support developers and designers during their development tasks. Semantic representation and use of that knowledge allow a better management and efficient reuse during development process.

## 29.4 The Global Framework Design

### *29.4.1 Separation of Concern Principle*

Independently from the technology being used and with regard to requirements previously identified, high cohesion and loose coupling are two strong conditions to the problems of reusability, maintainability, flexibility, scalability, and adaptability. These software quality characteristics are usually addressed by the so-called separation of concern principle (Familiar 2015).

This principle when used in its full meaning could not only be applied to software components (i.e., functional code) but also to data models and structures.

To achieve this goal, in the context of the present work, both micro-services and modular ontological models paradigms are used.

The MVC paradigm aims, mainly, to separate the business logic (i.e., the model) from its representation (i.e., the view). It is also used in both client- and server-side. In this context, core business logic lies on server-side, while views and content personalization and adaptation are carried on client-side.

### *29.4.2 Gamification and Context Awareness as a Set of Micro-services*

Micro-services are small autonomous services that work together. They are fine-grained architecture components that have to be aligned to small business boundaries and deployed independently from other software on a platform such as a PaaS (platform as a service), an application server or also a Web server. Communication between services is made via well-defined APIs and network or local calls. Micro-services are good candidates to help achieving the separation of concern principle (Familiar 2015). Each service implements only a very small action or activity. Hence, it has a very limited responsibility.

Three main categories of micro-services are firstly identified. The first category deals with business core-related services. These services are domain specific. Examples of business domains are education, training, health, marketing, commerce, etc. The second category deals with gamification, while the third one is more concerned with aspects related to context management and context awareness. However, a fourth category is required to act as a bridge between the business core logic and context-aware gamification aspects.

In order to provide the most fitted gamified experience to the end user and help to align gamification with business goals (e.g., intended learning outcomes achievement for education or best seller achievement for commerce) and business strategies (e.g., adopt active pedagogy for education, propose suitable discount for commerce), the user's interactions with the core business as well as her traceability and achievements have to be managed independently.

In Table 29.1, a taxonomy of main services is provided. This taxonomy specifies also many hierarchical levels within categories of services where each level identifies when possible a more detailed definition and classification of micro-services.

It is worth noting that micro-services provided by the framework are intended to act and operate on the ontological models. These latter are considered as their underlying data models. The framework's micro-services are also compliant to the REST style (Fielding 2000). This means that the notion of resource, including its representation, and its relationships with other resources is considered as a key component that is managed by the framework's micro-services. The resources' relationships allow not only to retrieve services' results but also to enhance the user's experience by providing possible state transitions between the application's states. This helps specifically developers to consider and model the overall system's structure as a set of networked resources and grants their integration and interoperability with gamification micro-services.

**Table 29.1** The frameworks, micro-services, and taxonomy

| Category | Level 1 services | Level 2 services | Purpose | Examples of specific services | Intended user |
|---|---|---|---|---|---|
| 1. | Business goals manager | | Define and update business goals | Goal creator | Business domain expert |
| | Business goal-achievements broker | | Maps business goals to user's achievements | Goal-achievement comparator | Gamification developer |
| | Business process/activity manager | | Implements business models, defines, updates business activity | | Business developer |
| 2. | Game element manager | Challenge manager | Defines and adapts game elements | | Gamification designer and developer |
| | | Points manager | | Points updater | |
| | | Badges manager | | Badge initializer | |
| | | Levels manager | | | |
| | | Achievements manager | | | |
| | | Rewards manager | | Rewards chooser | |
| | | Leader board manager | | | |
| | Game logic manager | Completion logic manager | Defines and adapts game logic | Completion logic verifier | Business experts and gamification designer and developer |
| | | Rules manager | | | |
| | Metrics manager | Motivation Metrics Manager | Defines and implements metrics processing | Motivation calculator | |
| | | Engagement metrics manger | | | |
| | | Fun metrics manager | | | |
| 3. | Context detection | User's experiences tracking | To be able to valuate every user's interaction or location | | Context developer and gamification developer |
| | | User's location detection | | GPS-based service | |
| | | Copresence of other players | To engage the group in a gamified experience | | |
| | | The application's state and structure | To be able to adapt or reconfigure the app's structure | Component remover | |
| | | Manager | | | |

| | | | | | |
|---|---|---|---|---|---|
| | Context analysis | Context data filtering | Removes irrelevant data | | |
| | | Reasoning and deriving contextual data | | Inference engine | |
| | Adaptation | HCI adaptation | | Visual component adapter | HCI developer |
| | | Resources and representation state adaptation | | | Business or gamification developer |
| | | System structure adaptation | | | |
| | | Transition adaptation (inter-resources links adaptation, intra-resources links adaptation) | | Transition remover | |
| 4. | Business-driven decision-maker | Decisions on business goals and challenges adaptation | Allows to display the relevant decisions to be made | | Business experts, gamification and context developer |
| | | Mapping business challenge to possible game challenge | | | |
| | Gamification metrics decision-maker | Decisions on gamification metrics adaptation | | | |
| | Game element decision-maker | Decisions on each game element adaptation | | | |
| | Game logic decision-maker | Decisions on game logic adaptation | | Game logic adaptation decider | |
| | HCI decision-maker | Decision on HCI adaptation | | | HCI developer |

### 29.4.3 Game Mechanics and Context as a Set of Ontology Modules

Ontology engineering methodologies promote the following basic phases:

1. Ontology specification specifies the ontology purpose, domain, and scope, and it requires to decide whether or not to reuse existing ontologies or to adopt modularity principles.
2. Ontology conceptualization in which the important terms of the ontology are enumerated, taxonomies (i.e., classes and classes hierarchies) are defined, and binary relationships, class and instance attributes or properties, formal axioms and rules, and, finally, instances are built and described.
3. Ontology formalization (in a formal or semiformal) model.
4. Ontology implementation and validation using an ontology development framework or a programming environment (Grüninger and Fox 1995).

Modularity has become a key aspect in ontology engineering (Abbes et al. 2012). However, it raises several issues such as those related to the ontology module structures' representation and the way reasoning is performed over those modules or over the overall ontology. Indeed, different reasons such as performance, maintainability, reusability, and collaboration among several knowledge engineers advocate the decomposition of ontologies into smaller modules or composition of a bigger ontology from smaller knowledge chunks.

In the context of the present work, two main reasons have guided the design toward modular ontological models. The first one is the separation of concern principle that naturally drives decomposition of knowledge pertaining to different domains into different but interrelated modules with respect to high cohesion and loose coupling. The second reason is related to reusability and extensibility or adaptability easiness. This means that even within the same domain, changes may occur either by adding new concepts, relationships, or axioms or by removing already defined ones. Other changes can be performed over inter-module links, which grant the flexibility to create different composed ontologies by just changing links and acting on mappings between ontology elements. Therefore, ontological modularity, in this context, has been driven by the semantics of the application domain (i.e., the context-aware gamification framework). Consequently, ontology modules are delimited accordingly to the framework's identified sub-domains each of which attempting to answer a specific application requirement.

Table 29.2 summarizes the different ontological modules organized firstly by domain and further by sub-domain**.**

Despite the importance of this set of ontological modules, only those related to context and gamification are considered in the scope of the present chapter. However, the business domain is considered as a generic domain that may be specialized to specific domains such as training, learning, health, marketing, cultural heritage, tourism, etc. Moreover, in realistic contexts, a given user may experiment, during a given period, different activities related to different domains. A typical example of

**Table 29.2** Modules, domains, and sub-domains

| Domain | Sub-domain | Module |
|---|---|---|
| Context | Environment | Location, time, places, provided services, and activities |
| | Device | Characteristics, platform, etc. |
| | System (application) | System structure or architecture |
| | | Resources and relationships |
| | | System properties |
| | | Components |
| | User | User profile |
| | | Preferences, traits, desires, goals, knowledge, skills |
| | User activity | Activity |
| | Group | Collective preferences, skills |
| | User experience | |
| Gamification | Game mechanics | Points, badges, levels, rewards |
| | Game dynamics | Achievements, completion logic, actions |
| | Game aesthetics | Outcomes, fun, flow, engagement, motivation |
| | Gamification strategies and good practices | |
| Business | Business goals | Goals hierarchy |
| | Business challenges | Challenges hierarchy |
| | Business processes | Business activity |

such a situation is the set of activities that students or other actors may encounter in a campus common day life. Indeed, a student may span different contexts while carrying out different educational or recreational activities. Therefore, the concept of activity is intentionally kept generic. It is additionally considered as a central concept that will drive possible relationships between ontological modules. It will guide specifically gamification and context-awareness strategies. As illustrated in Table 29.2, the activity concept is related to at least four ontological modules to express (1) possible activities provided by the environment, (2) concrete or current activity to be performed by a user, (3) the sequence of activities already done and that form the user's experience, and (4) the business activity that is related to a given business domain with possible business challenges and goals.

#### 29.4.3.1 The Context Ontology

The context ontology describes concepts related to context elements with a specific focus on the activity concept. It constitutes a different perspective of the ontology developed in Khemaja and Buendia (2015). It also integrates concepts inspired from the Experience API (aka Tin Can API specification) ontology developed in Taamallah and Khemaja (2014) and Taamallah and Khemaja (2015) (Fig. 29.1).

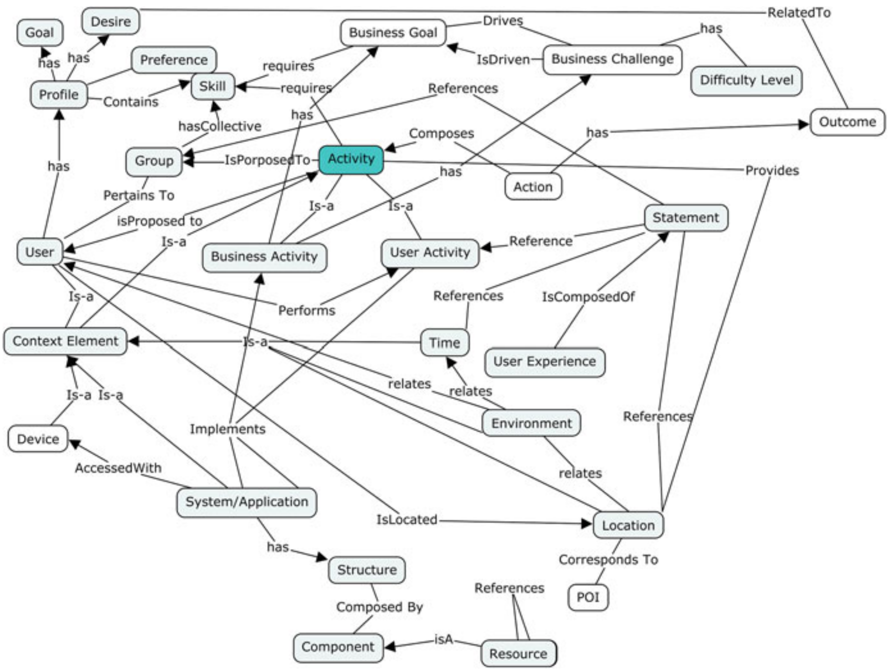


**Fig. 29.1** The context ontology model

In order to define the domain and scope of an ontology, a list of competency questions that it should be able to answer is gathered. Examples of main competency questions that the ontology attempts to answer are the following:

Q1: What kind of current or possible activity a given user can do individually or in group?
Q2: What are the context elements that formed a given user's experience?
Q3: What business goals and or challenges are achieved by a given business activity?

The answer to Q1 is enabled, thanks to the relationship "IsProposed" that relates the concept "activity" to the concepts "group" and "user."

Logical rules are also applied to the context ontology in order to infer additional knowledge. Following are examples of possible rules:

*When a user's and a given activity's locations are the same, the user may be asked to perform the activity.*

User(U) ∧ isLocated(U, L1) ∧ Activity(A) ∧ isLocated (A, L2) ∧ SameAs (L1, L2) →IsProposedTo (A, U)

(continued)

*When two users are colocated, the activity performed by the first user may be proposed to the second user to encourage them to collaborate.*

User(U1) ∧ isLocated(U, L1) ∧ User(U2) ∧ isLocated (U2, L2) ∧ SameAs (L1, L2) ∧ Performs (U1, A) →IsProposedTo (A, U2)

#### 29.4.3.2 The Gamification Ontology

The gamification ontology describes concepts related to game elements such as points, leader boards, challenges, game dynamics and their corresponding aesthetics, as well as the process, strategies, and good practices of gamification applied to a given activity and how the resulting activity may be experienced by its users.

The development methodology is based on a literature review about gamification. The ontology purposes and competency question identification are based on the scenario described and analyzed in Sect. 29.3. Main purposes are therefore addressed to:

1. Help the developer to gamify a given activity by selecting relevant game elements. This requires the ontology to represent game element types, their models, their methods of operation, and how the game element is related to common game metrics such as fun, engagement, motivation, etc.
2. Manage gamification data that relates it to the user's experience and context for decision-making. This requires that the ontology allows reasoning over user experience data to drive further progress. This either operates on the current activity with the same mechanics or operates on adding new game elements, rules, etc.

The gamification ontology is built around two main ontological design patterns. The first one describes the MDA (mechanics, dynamics, and aesthetics) pattern (Hunicke et al. 2004). It defines three different perspectives. The game mechanics perspective describes each game element or game element taxonomy with a focus of its operation mode, its appearance, and the game logic it could be associated to.

The game dynamics perspective describes possible users' interactions among game elements. This perspective considers specifically the challenges associated with a given activity, the user's achievements which are constrained by a completion logic (i.e., a set of requirements and conditions among users' actions that is worth an achievement) (Hamari and Eranti 2011).

Finally, the game aesthetics perspective enables to define the outcome related to the players' interactions with game mechanics. It defines specifically the player's perception related to obtained rewards. It also defines gamification metrics that may compose an activity-related dashboard allowing business and gamification experts to get further decision-making.

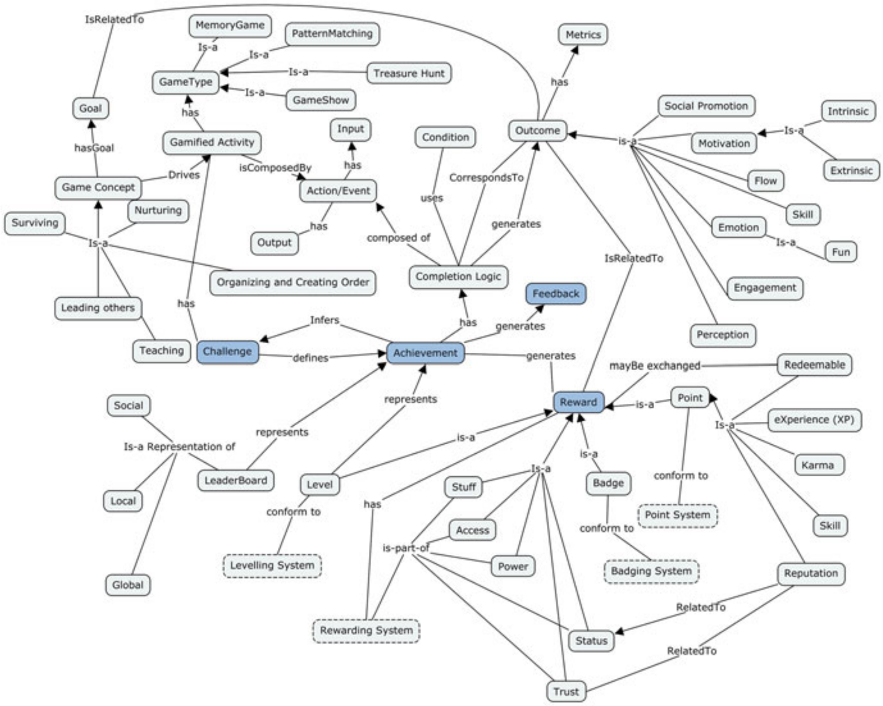


**Fig. 29.2** The gamification ontology model

These three perspectives are equally used for defining the second ontological design pattern related to the challenge-achievement-reward-feedback game loop pattern (Fig. 29.2).

#### 29.4.3.3 Ontology Modules Connections

As illustrated in Fig. 29.3, on top of gamification and context concepts and relationships lays the process of gamification defined as the process of using game thinking to engage audiences (Zichermann and Cunningham 2011). It allows to combine these elements in different ways and so to provide a gamified experience or, more specifically, a gamified activity. Two possible scenarios are, namely, considered; either gamification is integrated to an existing business activity (i.e., gamified activity in Fig. 29.1 matches exactly the gamified activity in Fig. 29.2) or a gamified activity is created and proposed to the user before or after the given business activity.

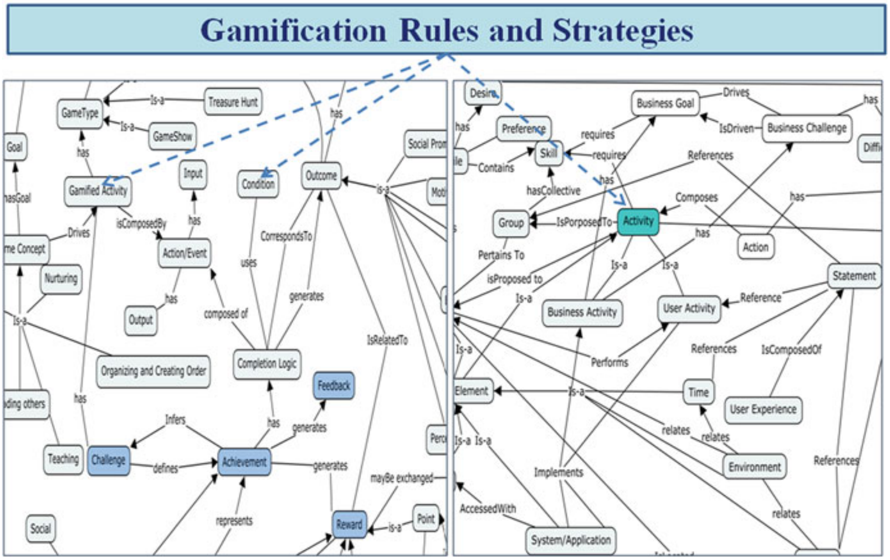


**Fig. 29.3** Ontology connections

Gamification strategies or heuristics can therefore be expressed with logical rules as illustrated in the following examples:

*For an existing Business Activity related to a Business Goal that requires one or more specific skills it is better to select a challenge that reinforces those skills.*

$\text{BusinessActivity(A)} \wedge \text{hasBusinessGoal(BG, A)} \wedge \text{requiresSkill(BG, S)} \wedge \text{Challenge(C)} \wedge \text{hasOutcome (C, S)} \rightarrow \text{Selected (C, true)}$

*For an existing Activity that may be proposed to a given user with specific desires, it is better to select a challenge that reinforces those desires.*

$\text{Activity(A)} \wedge \text{IsProposedTo(A, U)} \wedge \text{hasDesire(U, D)} \wedge \text{Challenge(C)} \wedge \text{hasOutcome (C, O)} \wedge \text{Matches (D, O)} \rightarrow \text{Selected (C, true)}$

*Each Action composing an activity is worth Skill points.*

$\text{Activity (A)} \wedge \text{Action (Ac)} \wedge \text{IsComposedBy(Ac, A)} \wedge \text{Point(P)} \rightarrow \text{Skill (P, true)}$

The following rules apply to the use of game mechanics accordingly to a given game concept or goal:

*Being Fame requires the use of Global Leader Board while the desire of Collecting is suitable with redeemable Points.*

$$\text{Goal (G)} \wedge \text{BeingFame (G)} \wedge \text{LeaderBoard(L)} \rightarrow \text{Global(L)}$$

$$\text{Goal (G)} \wedge \text{Collecting (G)} \wedge \text{Point(P)} \rightarrow \text{Redeemable (P, true)}$$

The following rules apply to gamified activities to be created accordingly to user's goals:

*If the Goal is of type Collecting, then the Gamified Activity could be of Geocaching type*:

$$\text{Goal (G)} \wedge \text{Collecting (G)} \wedge \text{GamifiedActivity (GA)} \rightarrow \text{hasType(GA, Geocaching)}$$

$$\text{Goal (G)} \wedge \text{LeadingOthers(G)} \wedge \text{GamifiedActivity (GA)} \wedge \text{Challenge (C)} \wedge \text{hasChallenge (GA, C)} \rightarrow \text{Collaborative(C)}$$

Finally, these examples of rules deal with context awareness; for instance:

*If the user's profile changes with a new desire, a new activity is proposed with an outcome that fulfills the new desire:*

$$\text{User(U)} \wedge \text{hasProfile(U, P)} \wedge \text{hasDesire(P,D)} \wedge \text{isRelated (O, D)} \wedge \text{Outcome(O)} \wedge \text{isGeneratedBy (O, Ac)} \wedge \text{Composes(A,Ac)} \rightarrow \text{IsProposedTo (A, U)}$$

## 29.5 The Framework's Implementation and Deployment

With regard to requirements identified in Sect. 29.3.2 and design principles highlighted in Sect. 29.4.1, a reconfigurable micro-services framework has been used for both implementation and deployment. This framework relies on:

1. The OSGi technology (Hall et al. 2011) that provides platforms supporting dynamic services deployment and a standardized component-oriented computing environment for Java application development, composition, and execution (De Castro Alves 2011)
2. A set of OSGi bundles (third-party libraries) for developing and deploying the framework's component as a set of restful resources
3. A set of OSGi bundles for processing and reasoning over ontologies

All OSGi components have been developed and tested for the Apache Félix OSGi implementation and the Apache Jena Engine. The ontologies has been implemented in the OWL2 (Ontology Web Language version 2) language by making use of the Protégé ontology development environment.

### *29.5.1 Context-Aware Gamified Apps Design and Development Processes*

The developed micro-services of the Framework open up many opportunities and possible use cases for designing, developing, and also deploying context-aware gamified apps.

The first use case considers the micro-services of the Framework as a means to interact with a context-aware gamification knowledge base and thus helps identifying ideas and hints on how gamification and context awareness could be integrated within a given app (see Fig. 29.4, components referenced with number one).

The second use case applies to client-server-oriented gamified apps where the framework's micro-services form the server-side (back end) of the app. It allows the developer to invoke micro-services to generate automatically gamified activity-related knowledge and then to manage the user's interactions and experience. This use case requires that designers and developers consider the micro-services results and develop consequently the client-side (front-end) components and user interfaces (components referenced with numbers one and two in Fig. 29.4).

Finally, a more elaborated use case considers the use of a mobile app development framework (e.g., ionic framework working on top of AngularJS and Apache Cordova for cross mobile platform deployment) that helps developers to reuse useful pre-built front-end components, templates, and services and to allow the developed components to interact with the framework's micro-services.

The process in Fig. 29.5 details the second use case. Each activity in the process is associated to a micro-service invocation. More descriptive results of micro-services invocations are illustrated in Sect. 29.5.2.

This process aims to gamify a given business activity. It is composed by tasks either associated to services (service task) or realized by a given user (user task):

| | | | |
|---|---|---|---|
| 1. | Identify business goals of the activity | 6. | For each game challenge, identify an achievement |
| 2. | Identify actions and outcomes of the activity | 7. | For each achievement, retrieve the completion logic |
| 3. | Retrieve game challenges that best fit to business goals of the activity | 8. | Verify mappings between completion logic actions and the activity actions |
| 4. | Classify game challenges accordingly to their levels | 9. | For each achievement, retrieve possible rewards |
| 5. | If exact match insert completion logic to activity actions else insert the game instance before or after the business activity | 10. | Implement completion logic actions and their corresponding user interface |

### *29.5.2 Proof of Concept: Case Study and Micro-services Prototype*

In order to show the framework application, a case study is presented about the development of a gamified app in the context of a university campus. This case study deals with interactions that several profiles of campus users can have and how gamification issues help them in such interactions. Furthermore, a set of micro-services have been developed to illustrate the framework's application.

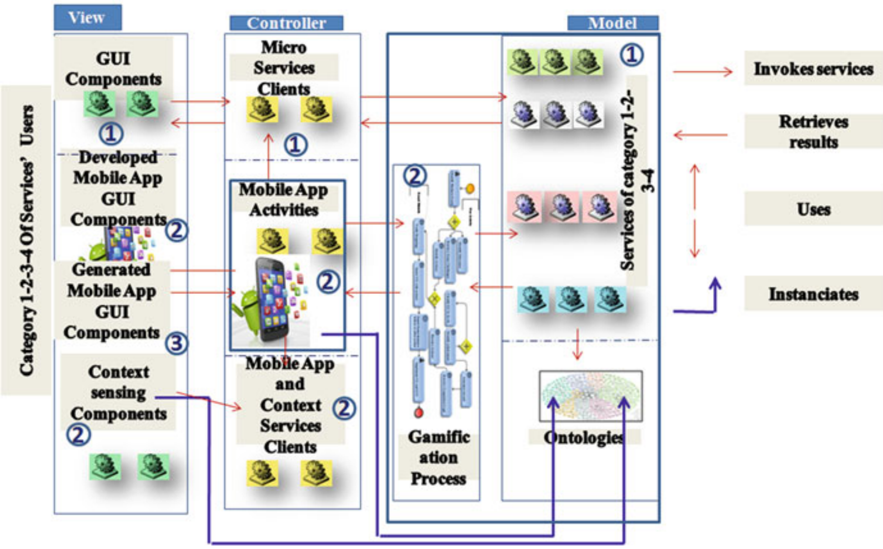


**Fig. 29.4** The framework's use cases

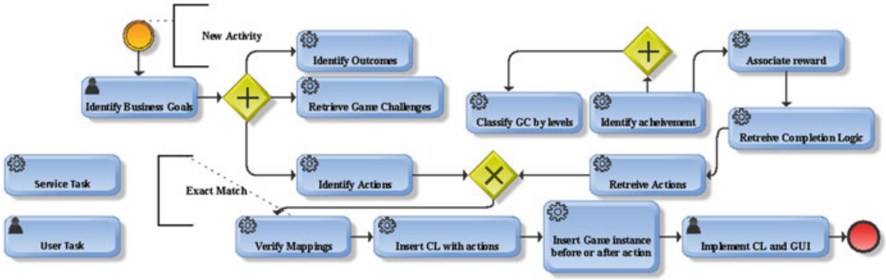


**Fig. 29.5** Gamification process

#### 29.5.2.1 The Mobile App Features' Description

A university campus is a complex environment where different kinds of interactions take place including those related to instructional and learning tasks. Most of these interactions require gathering contextual information from the campus facilities, platforms, services, or people that are part of this environment. Moreover, there are several user profiles who are involved in the campus and not only students, lecturers, or university employees but also professionals, foreign visitors, high school students, or their families.

Gamification can be incorporated in many of these interactions, but the current study is bounded to a reduced set of them. In this case, a typical event which is produced every year in a university campus has been selected and linked with the visit of new comers (high school students as potential freshmen) to know the campus. They are not usually familiar with the campus environment, and a mobile app could give them a support including some play options. For example, these visitors can be invited to discover building or services that could be useful in their future campus life. Even, campuses increasingly provide spaces for exhibiting artistic masterpieces or celebrating cultural events in which new comers could participate.

Table 29.3 shows several activities or actions which can be related with this Welcome to the Campus event. For example, a first step could be organizing a starting meeting with new comers' families to offer them a presentation about the campus. From this starting campus access, visitors can be interested in curriculum information about the university studies or register details in the Student Service. Moreover, they can get information about accommodation or eating facilities around the campus or perform some kind of cultural tour visiting art pieces. Information about challenges that can be associated to these activities is also displayed on this table such as getting a healthy diet when eating or having an important number of visitors in an art exhibition.

**Table 29.3** Possible users' activities

| Activity domain | Location | Activity example | Description | Challenges |
|---|---|---|---|---|
| Campus access | Entry meeting point | Search for the location | Starting meeting either for students or other kind of users | Highest attendance of users to meetings |
| Student Service | Main student office | Ask and collect information | Delivery of documents such as campus guides of studies leaflets | Largest dissemination of existing academic documents |
| Accommodation | Student houses | Seek and select accommodation | Guides about near accommodation places (houses, apartments . . . ) | Highest matching degree with users' interests and hobbies |
| Eating service | Dining halls | Find the relevant places | Selection of meals according to user requirements or needs | Widest range of healthy meals |
| Art exhibition | Campus galleries or outdoor museums | Find art piece locations | Looking at art pieces around the campus | Largest dissemination of campus art exhibitions |
| Finance accounts | Bank offices | Perform financial transaction | Searching for an ATM or doing a fees payment | Widest range of payment methods |
| Health services | Pharmacy/clinical | Ask for medical service in time | Medical assistance or getting pharmacy drugs | Largest use of medical attention points |
| Learning a foreign language | Language Learning Institute | Perform assignments | Registering in language courses according to CEFREL levels | Highest level achievements for language skills |

An example of potential game applied to this context can deal with the "art exhibition" activity. It can be aimed at promoting orientation skills through geo-location tasks, observation abilities in case of an art exhibition, or encouraging initiative and/or decision-making attitudes when new comers have to choose an accommodation facility. Other game goals can address social skills when campus activities are carried out in groups or they require leadership ability. Achievements and rewards can be provided to new comers according to the performed activities.

localhost:8080/Service/BusinessActivity

| Activity | BusinessChallenge | BusinessGoal | Action |
|---|---|---|---|
| ctx:DiscoverSculptures | ctx:PublishBestReport | ctx:KnowHistory | ctx:WriteReport |
| ctx:DiscoverSculptures | ctx:PublishBestReport | ctx:KnowHistory | ctx:LocalizeSculpture |
| ctx:ArtExibition | ctx:CollectFeedback | ctx:DissiminateArt | ctx:QuestionAnswer |
| ctx:ArtExibition | ctx:CollectFeedback | ctx:DissiminateArt | ctx:LocalizeArtPiece |
| ctx:ArtExibition | ctx:CollectFeedback | ctx:DissiminateArt | ctx:InternetSearch |
| ctx:ArtExibition | ctx:CollectFeedback | ctx:DissiminateArt | ctx:InviteFriends |
| ctx:ArtExibition | ctx:HaveManyVisitors | ctx:DissiminateArt | ctx:QuestionAnswer |
| ctx:ArtExibition | ctx:HaveManyVisitors | ctx:DissiminateArt | ctx:LocalizeArtPiece |
| ctx:ArtExibition | ctx:HaveManyVisitors | ctx:DissiminateArt | ctx:InternetSearch |
| ctx:ArtExibition | ctx:HaveManyVisitors | ctx:DissiminateArt | ctx:InviteFriends |
| ctx:OrganizeVisits | ctx:HaveManyVisitors | ctx:PromoteTourism | ctx:TakePhotos |
| ctx:OrganizeVisits | ctx:HaveManyVisitors | ctx:PromoteTourism | ctx:ScheduleVisit |
| ctx:OrganizeVisits | ctx:HaveManyVisitors | ctx:PromoteTourism | ctx:MakeVisit |
| ctx:OrganizeVisits | ctx:HaveManyVisitors | ctx:PromoteTourism | ctx:IdentifyVisitPath |

**Fig. 29.6** Business activity challenge description

#### 29.5.2.2 The Framework's Usability

Two complementary perspectives related, respectively to the business and the gamification aspects are provided by the framework. For instance, the selected activity may have several business goals and business challenges and also could be associated to a gamified activity that helps in achieving its intended goals and challenges. In this context, the micro-services are invoked to infer and query the ontology knowledge and propose some gamified activity instances.

Figure 29.6 shows a set of items related to potential business activities that could be performed in a campus-based app. For example, the art exhibition activity may have a business challenge addressed to get an important number of visitors who can play actions like finding art pieces or searching information on them. Another type of business activity would be a visit arrangement with the same business challenge and game actions to schedule the visit timetable or organize the path to be followed.

These business challenges can be linked with patterns of games and their associated challenges. For example, a game addressed to guide users through different scenarios or collect several items or objects from them could agree with business challenges that aim to gather an important number of visitors, get the best score in a certain work, or collect the feedback from users who are visiting an exhibition (Fig. 29.7). Moreover, a visitor could invite colleagues or friends or also other unknown people to participate on activities which may be addressed by the "collecting pseudo" game challenge.

In Fig. 29.8, the gamification perspective relates a gamified activity to a possible game challenge identified previously in Fig. 29.7.

In Fig. 29.9, a list of available game concepts with corresponding goals enables to relate the game concept goal to possible outcomes and rewards. A game concept allows equally identifying game types and related gamified activities (Fig. 29.10).

localhost:8080/Service/GameChallenge

| BusinessChallenge | GameChallenge |
|---|---|
| ctx:PublishBestReport | cgo:CollectClues |
| ctx:HaveManyVisitors | cgo:OrganizeMeeting |
| ctx:HaveManyVisitors | cgo:GuidePeople |
| ctx:HaveManyVisitors | cgo:CollectPseudos |

**Fig. 29.7** Possible game challenges

localhost:8080/Service/GamifiedActivity

| GamifiedActivity | GameChallenge |
|---|---|
| cgo:HealthGame | cgo:FindSupporters |
| cgo:ArtShowGame | cgo:GuidePeople |

**Fig. 29.8** Business activity challenge description

localhost:8080/Service/GameConcept

| Reward | Outcome | Goal | GameConcept |
|---|---|---|---|
| cgo:Reputation | cgo:ManyFriends | cgo:Reputation | cgo:Teaching |
| cgo:Skill | cgo:Distress | cgo:Skill | cgo:Surviving |
| cgo:Knowledge | cgo:Distress | cgo:Skill | cgo:Surviving |
| cgo:Skill | cgo:Distress | cgo:Knowledge | cgo:Surviving |
| cgo:Knowledge | cgo:Distress | cgo:Knowledge | cgo:Surviving |
| cgo:Skill | cgo:Distress | cgo:Skill | cgo:OrganizingandOrdering |
| cgo:Knowledge | cgo:Distress | cgo:Skill | cgo:OrganizingandOrdering |
| cgo:skillPoints | cgo:Engage | cgo:Payoff | cgo:Nurturing |

**Fig. 29.9** Game concepts with corresponding goals

Figure 29.11 shows that the framework allows to identify a full gamified set of activity instances relating challenges, achievements, and completion logics to possible rewards.

It displays, therefore, the game elements that could support gamified activities such as those previously presented. An accommodation game can consist in a contest or competition (battle type) where opponents may offer to user bad food and invite her to eat it. Moreover, a game based in art show could match a puzzle pattern or a discover pattern in order to promote searching information about art pieces or watching images to discover some weird object that has been placed.

Finally, Fig. 29.12 shows a simple adaptation of completion logic that leads to automatically adapt all other game elements.

localhost:8080/Service/GameType

| GamifiedActivity | GameType | GameConcept |
|---|---|---|
| cgo:HealthGame | cgo:PatternMatching | cgo:Surviving |
| cgo:HealthGame | cgo:PatternMatching | cgo:Nurturing |
| cgo:HealthGame | cgo:Battle | cgo:Surviving |
| cgo:HealthGame | cgo:Battle | cgo:Nurturing |
| cgo:CampusAccessGame | cgo:MemoryGame | cgo:Teaching |
| cgo:ArtShowGame | cgo:Puzzle | cgo:OrganizingandOrdering |
| cgo:ArtShowGame | cgo:Puzzle | cgo:LeadingOthers |
| cgo:ArtShowGame | cgo:GameShow | cgo:OrganizingandOrdering |
| cgo:ArtShowGame | cgo:GameShow | cgo:LeadingOthers |
| cgo:AccomodationGame | cgo:Battle | cgo:Surviving |

**Fig. 29.10** Game types and related gamified activities

localhost:8080/Service/GamifiedActivityInstances

| GamifiedActivity | Challenge | CompletionLogic | Action | Condition | Achievement | Reward |
|---|---|---|---|---|---|---|
| cgo:ArtShowGame | cgo:GuidePeople | cgo:CLC2 | cgo:Invite | cgo:PeopleNumberequals5 | cgo:GuideFivePeople | cgo:1000Point |
| cgo:HealthGame | cgo:FindSupporters | cgo:CLC3 | cgo:AskForPseudo | cgo:PeopleNumberequals20 | cgo:HaveTwentySupporter | cgo:2000Point |

**Fig. 29.11** Gamified activity instances

localhost:8080/Service/GamifiedActivityInstances

| GamifiedActivity | Challenge | CompletionLogic | Action | Condition | Achievement | Reward |
|---|---|---|---|---|---|---|
| cgo:ArtShowGame | cgo:CollectPseudos | cgo:CLC4 | cgo:GuidePeople | cgo:PeopleNumberequals100 | cgo:ObtainOneHundredPseudos | cgo:GoldBadge |
| cgo:HealthGame | cgo:FindSupporters | cgo:CLC3 | cgo:AskForPseudo | cgo:PeopleNumberequals20 | cgo:HaveTwentySupporter | cgo:2000Point |

**Fig. 29.12** Adapted gamified activity instances

This case study around the gamification process of a mobile app oriented to campus new comers showed that main competency questions required from the ontologies can be answered. It also showed that the micro-services have provided these answers without the need that the developer manipulates ontologies or has to be skilled for doing so.

## 29.6 Conclusion and Future Work

The present chapter has dealt with issues related to gamification and context-aware mobile app development. It highlighted main requirements of these applications and the need of relevant and semantic-based development frameworks.

It therefore, attempted to design and develop a context-aware gamification framework providing both knowledge and good practices related to gamification and context awareness as a set of ontological modules and micro-services.

Main contributions of the proposal are the developed artifacts and their usability to address defined requirements. Moreover, those artifacts are generic enough to be reused to address many different scenarios related to gamification. They may also be reused for building game logic and mechanics for full-fledged SG.

In the very near future, results will be applied to help in developing and extending the framework to define client-side components of context-aware mobile apps. In this context, semantic Web service-based principles could be applied to client-side components or human-communication interfaces in order to avoid development dependency among specific technologies and grant business logic and HCI adaptation in the client-side.

A second very important issue is that related to the gamification domain itself. As gamification is considered a very fast-moving trend, ideas, strategies, and good practices have to evolve in the same fast pace. Therefore, future work would focus on an approach that could address ontology learning and population in a flexible way. Such an approach could specifically be based on both automatic semantic annotations and Web mining and analytic approaches. Moreover, ontology instances related to the mobile app activities and actions could be automated thanks to reverse engineering and analysis approaches.

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