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Editorial by the Guest Editors
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This issue of EJEL is dedicated to Game-Based Learning and, in particular, to ECGBL 2013 – the 7th European Conference on Game-Based Learning. Therefore, we would like to thank the editors of EJEL for allowing us to promote an important area of the use of technology for learning in such a relevant journal.

Games are structured contexts where the player has clear objectives, with victory as the end goal. The player must solve problems, overcome challenges and face opponents (real or game characters) but always respecting a clearly-defined set of rules. More than simple entertainment contexts, games have been shown to promote learning and the development of personal and social skills like socialization, teamwork, leadership, decision making and collaborative learning. Therefore they have been successfully used in training, in formal education (classroom and school context) and also in non-formal education (outside the school context).

The European Conference on Game-Based Learning – ECGBL, has been a reference forum to exchange ideas and best practice among researchers and practitioners. The 2013 edition took place in Porto, last October, and was another opportunity for the presentation of research, theory, application, practice and validation in this field. The conference partnered with SEGAN – Serious Games Network, a European community of practice that gathers more than 500 individuals interested in this area, providing a valuable synergy.

The contribution of the keynote speakers, Prof. Baltasar Fernández-Manjón, from the Complutense University of Madrid and Dr Paulo J. Gomes, from Bigmoon Studios, were paramount by addressing research and practical aspects of GBL. But above all, it was the very high number of contributions ranging from theoretical and empirical studies, work-in-progress, PhD research, to product demonstrations and a game competition that created the conditions for the success of the conference. From that large number of contributions, we selected six that demonstrate the quality of the overall conference and the large scope of targets, topics, technologies and methodologies that GBL already addresses.
Malliarakis et al present a framework intended for computer programming-specific educational games and instantiated a specific game-example with this purpose. Authors reflect that the need for this framework arises from the necessity of adequate planning during the design of educational games, and thus the availability of adequate guidelines that include all characteristics that should be incorporated in such games.

Katmada et al designed, developed and evaluated an online game for elementary and middle school mathematics teaching and learning. Study results indicated that the students’ opinion about the game was positive, and suggest that with some extensions the game could be used as an effective learning tool.

Dourda proposes an educational design proposal that combines Game-based Learning (GBL) and Content and Language Integrated Learning (CLIL). The author designed an educational geography computer game for 11 to 12-year-old students based on problem solving challenges regarding the use of geography in realistic contexts. The findings of this case study suggest that foreign language learning can successfully take place within a geography game-based learning environment, and they underscore the efficacy of approaching GBL in terms of performance.

Magnussen et al report results from the design and testing of an educational version of a scientific discovery game that allows players to help solve authentic scientific challenges. Authors wanted to investigate if and how this type of game concept could strengthen authentic experimental practice and the creation of new knowledge in science education and found that for high school students the aspects of playing the game and were highly motivating for students.

Majgaard studied how engineering students could develop programming skills by creating their own games, thereby applying their game-playing experiences to gain knowledge about game design. The didactic approach was based on the constructionist and reflective learning philosophies. The author found that although the constructionist learning approach promoted creative and innovative learning, it did not develop competencies in articulation and analysis. But by considering retrospective reflective discussions in the classroom and their programming experiences it was possible to reinforce the learning process.

Pløhn addresses the concept of pervasive gaming as a new and emerging gaming genre where the physical and social aspects of the real world are integrated into the game and blend into the player’s everyday life. The author designed and developed a prototype of a playable pervasive game to support learning in university studies. Study results showed that the game became pervasive and a part of the students/players everyday life. Players found the game exciting and fun to play, but that the academic tasks and riddles that they had to solve during the game were too easy to solve.
We really hope you enjoy this special issue of EJEL, at least as much as we did when reading and selecting these articles.

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Editors
Implementing a Game for Supporting Learning in Mathematics

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Abstract: This paper focuses on the design, implementation and evaluation of an online game for elementary and middle school mathematics. Its aim is twofold: (a) the development of the prototype of a flexible and adaptable computer game, and (b) the evaluation of this prototype, as to its usability and technical aspects. The particular computer game was created in an attempt to facilitate the teaching of mathematics, a subject that is often regarded as complicated by students of all ages. Apart from the game, an administration website was also constructed, so that the educator can configure the game, without that requiring any programming skills. More specifically, the educator can use the administration website in order to alter several of the game’s parameters, such as the content and total number of its questions. The game was evaluated in real school settings, both through a pilot study with 12 students and a longterm intervention with 37 students that lasted 14 weeks. The results indicated that the students’ opinion about the game was positive, and suggest that with some extensions the game could be used as an effective learning tool. Finally, some corresponding conclusions and future improvements to the game are being discussed on the basis of the findings.

Keywords: 2D Digital Game Based Learning, Primary education, Secondary Education, Mathematics

1. Introduction

Research into the education of mathematics has long demonstrated that math learning difficulties is a common and important problem among students of all ages. According to Garnett (1998), many students face math learning problems of different types; these learning difficulties range from mild to severe, and require instructional attention and various treatment methods. Some of the most common math learning problems include: (a) difficulty memorizing basic number facts; (b) computational and arithmetic weakness; (c) confusion about terminology and the written symbolic notation system of school math; and (d) weak understanding of concepts due to visual-spatial organization deficits (Garnett, 1998). Apart from lower performance in math exercises and tests, these math learning disabilities can also result in avoidance behavior and negative perception of the particular subject. Often, students with math learning difficulties exhibit high math anxiety, which is defined as “a feeling of tension, apprehension, or fear that interferes with math performance” (Ashcraft, 2002). This math related problem was first reported by Dreger and Aiken (1957), who noticed that students demonstrated emotional reactions to arithmetic and mathematics. According to their study, math anxiety is distinct from general anxiety, not necessarily related to overall intelligence, and can contribute to poor performance in mathematics. These findings were substantiated and reinforced by more recent research (Richardson and Suinn, 1972; Tobias and Weissbrod, 1980; Wingfield and Meece, 1988; Ashcraft and Kirk, 2001), indicating that there is a negative correlation between math achievement and math anxiety.

One of the most detrimental consequences of math anxiety is that it can lead to unfavorable attitude towards the particular subject, as well as negative self-perceptions about one’s math abilities (Ashcraft, 2002). Consequently, highly math-anxious students also tend to avoid enrollment in math-related courses, as well as pursuing degrees or career paths based on mathematical or quantitative skills (Hembree, 1990; LeFevre, Kulak and Heymans, 1992). Hence, the educator should try to incorporate teaching methods that emphasize the value of mathematics, help students develop their math skills, and increase their self-efficacy beliefs (Meece, Eccles and Wingfield, 1990). Moreover, it is of utmost importance to help students acquire a positive perception of mathematics, as this is considered to be highly related to lower math anxiety and higher math
achievement (Hembree, 1990). This could be achieved though the use of computer games, since they encompass many characteristics that make them valuable tools for the educational process. More specifically, computer games promote active learning (Oblinger, 2004) and the development of various skills (McFarlane, Sparrowhawk and Heald, 2002), while they retain their entertainment and appealing qualities (Kafai, 2001).

So far, effective use of computer games for educational purposes has been reported in various subject areas, such as geography (Virvou, Katsionis and Manos, 2005; Tüzün et al., 2008), computer science (Papastergiou, 2008), health education (Dorman, 1997), and mathematics and sciences (Klawe 1999; Annetta et al., 2009). According to Ke (2009), who conducted a meta-analysis with 89 empirical studies on instructional gaming, computer games can affect favorably students’ motivation and learning in a multitude of educational settings, both formal and informal. Additionally, as Hays (2005) points out, specially designed instructional computer games can be of educational value. Nevertheless, it should be noted that the majority of the existing empirical studies are inconsistent due to divergent research, game, and learner variables, short-term experiments and interventions, and uncertain descriptions of the games that were used (Ke, 2009).

Accordingly, this study addresses the design and development of a computer game that could be utilized as an adaptable tool for the educational process. The purpose of the particular game would be to support the teaching of elementary and middle school mathematics, as a complementary learning tool that could enhance students’ motivation and engagement with the subject. Apart from the game, an administration website was also constructed, so that the educator can ensure that the game’s content aligns with the curriculum and the learning goals of the current lesson. Moreover, the educator can easily edit the game’s content and images, or upload new ones, without that requiring any programming or scripting skills. Concerning the game’s design, basic educational computer game design principles (Malone, 1980; Prensky, 2001; Hays, 2005; Fisch, 2005) were taken into account, so that the game would be educationally and motivationally effective. The game prototype was then evaluated both through a pilot study and a longterm (14 weeks) intervention, in order to detect any technical flaws, and to assess its usability and educational aspects, so that it could be revised and improved in subsequent editions.

Hence, this paper aims at presenting a concrete case study on the design and development of the game ‘Volcanic Riddles’, as well as the results of a more longitudinal evaluation study in real school settings, where the aforementioned game was used for the teaching of formal curricular material. In order to investigate the criteria mentioned above, the research questions of the particular study are the following:

**RQ1:** What is the students’ opinion regarding the usability of the ‘Volcanic Riddles’ game?

**RQ2:** In what educational context could this game be used by educators?

**RQ3:** Will the gender or grade of students affect their opinion about the usability of the ‘Volcanic Riddles’ game?

This paper is organized as follows: in the next section, the conceptual framework that inspired the design of the aforementioned game is being reported. More specifically, Digital Game-Based Learning, as well as several studies concerning the use of computer games in mathematics education are being thoroughly analyzed. Next, there is a presentation of the aforementioned game, and the principles that inspired its design. Afterwards, the basic features of a prototype of this game and the administration website are being presented, and, subsequently, there is a description of the evaluation studies of this game’s prototype. Finally, the results of the studies are being discussed, and some conclusions are drawn on the basis of the findings.
2. Conceptual framework

2.1 Young people and Digital Game-Based Learning

Recently, there has been an ongoing interest in the use of computer games for educational purposes, as a means to increase students' motivation, engagement and achievement in various subject areas.

This learning approach, which combines digital game-based activities and educational content, is often referred to as Digital Game-Based Learning (DGBL). DGBL is considered able to render the learning of difficult or uninteresting subjects more accessible, engaging, and enjoyable (Malone, 1980; Kafai, 2001). Indeed, computer games play an integral role in today’s children’s lives, being part of their culture and one of their most frequent and favored activities (Mumtaz, 2001; Fromme, 2003). The reason for that could be their intrinsically motivational appeal and the fascination they provoke to young people, by encompassing elements of curiosity, challenge, and fantasy (Malone, 1980). Moreover, it has been suggested that computer games have the ability to immerse players in a state of ‘flow’ (Csikszentmihalyi, 1990), characterized by deep and full involvement and enjoyment in the activity. This state of ‘flow’ was described by Csikszentmihalyi (1990: 4) as “the state in which people are so involved in an activity that nothing else seems to matter”. Additionally, scholars have argued that computer games could be more effective and more appropriate than traditional instructional methods for the current generation of learners, whose cognitive abilities and interests are influenced by digital games and technology (Facer, 2003; Srinivasan, Butler-Purry and Pedersen, 2008).

Given the benefits described above, DGBL has already been implemented in various sectors, with three different approaches that, according to Van Eck (2006), are the following: (a) students create their own educational games, with the aid of the educators, (b) educators use commercial games in class that have not been primarily developed for educational purposes, (c) educators use games in class specifically designed for education by other educators, instructional designers, and developers. These instructional games, also known as ‘serious games’, are usually designed for training purposes and have many applications in various fields, such as education, science, production, and health (Sawyer and Smith, 2008). Each of the three approaches to implementing DGBL has advantages of its own; however, the most prominent benefits that DGBL offers, in general, can be summarized as follows: (a) computer games can facilitate the acquisition and transfer of knowledge to new situations through feedback and self-assessment mechanisms (Oblinger, 2004); (b) they can also promote the development of problem-solving and memorization skills (Mcfarlane, Sparrowhawk and Heald, 2002); (c) they help students familiarize themselves with technology, as well as programming and computer science concepts (Kafai, 2001; Van Eck, 2006; Prensky, 2008); and (d) gaming is often a social activity, contributing to the development of the players’ social and emotional skills (Squire, 2003; Fromme, 2003; Oblinger, 2004).

Nevertheless, DGBL constitutes a relatively recent and still evolving instructional method, and there is a need for more empirical evidence that could validate its actual educational value, and show how it could be applied more effectively. As Hays (2005) points out, research has demonstrated that games can promote learning in various subject areas, however there is no proof that games can be used in all situations and for every instructional task. It is also important that students are provided with debriefing, feedback, and support from the educators during the DGBL activities (Hays, 2005). Moreover, there are many practical issues that may deter the educator from using computer games in the classroom. A common impediment is that many times the game’s content is not correct or it does not align with the curriculum and the learning objectives of the classroom (Kirriemuir and McFarlane, 2003; Fisch, 2005). Also, teachers often encounter difficulties in identifying the educational components of a game, as well as integrating the game in the traditional educational process (Kirriemuir and McFarlane, 2003; Baek, 2008). Additionally, many contemporary complex games require new hardware and plenty of time, and thus they cannot be played in the classroom (Kirriemuir and McFarlane, 2003). Lastly, a frequent concern of educators and parents alike is the possible negative effects of gaming on children, such as addiction and overly competitive behavior (Baek, 2008).
2.2 Review of research on computer games for mathematics

There are several studies that report on the use of commercial computer games for mathematics, or present the development and evaluation of instructional games designed for the specific subject. As indicated by the following review of relevant studies, computer games can increase students’ math achievement and performance, and promote positive attitudes towards mathematics. For instance, in a recent study, Pareto et al. (2011), created a teachable-agent arithmetic game that aims in training basic arithmetics skills. The game was evaluated in a study with 153 participants, consisting of 3rd and 5th grade students. The results indicate that the game helped students improve their math performance and self-efficacy beliefs. Ahmad and Latih (2010) describe the development of an educational math game on fractions for primary school students. Similarly, Lee (2009) report on the creation and evaluation of an education game on fractions and mention that it improved students’ understanding and performance.

Concerning the use of commercial games for mathematics, Zavaleta et al. (2005) suggest in their study that the use of a commercial game for elementary school algebra enhanced students’ achievement. Kebritchi, Hirumi, and Bai (2010) investigated the impact of commercial math games on 193 high school students’ math performance, with positive results concerning the student’s perception of mathematics, motivation, and achievement. Ke and Grabowski (2007) examined the effects of the use of adventure games on 125 5th grade students that were assigned to three groups: cooperative game playing group, competitive game playing group, and no game playing group. According to their findings, after the four-week intervention the two game playing groups had better math performance, while the cooperative game playing group had better attitude towards the subject, compared to the other conditions. In another study, Ke (2008) examined the effects of the use of computer games on 4th and 5th grade students that were enrolled in a five-week summer math program, with positive results concerning the students’ attitude towards math. More recently, Kim and Chang (2010) performed regression analyses using 170,000 4th grade students, demonstrating that math computer games had a positive effect on male minority students.

Other studies focus on the use of math computer games for the remediation of specific deficits, such as dyscalculia. For example, Wilson et al. (2006) created an adaptive computer game for dyscalculia and tested it in a five-week evaluation study with nine children with math learning difficulties. The results indicated an increase in the children’s math performance on core number sense tasks, as well as an improvement as regards their confidence in their mathematical abilities. Regarding any pertinent research projects, the E-GEMS (‘Electronic Games for Education in Math and Science’, http://www.cs.ubc.ca/nest/egems/) project contributed on the development of various educational games that increased student engagement and achievement, and produced several design heuristics (Klawe & Phillips, 1995).

3. Design of the game

3.1 Basic features of educational games

According to Malone (1980), instructional designers should try to create intrinsically motivating educational environments that would help students learn in an effortless and engaging way. Computer games, in particular, contain the following three elements that make them so interesting, and can be used in order to motivate the learner: challenge, fantasy, and curiosity (Malone, 1980). Malone (1980) draws upon these observations in order to develop a set of guidelines for the design of effective and motivational instructional computer games. In accordance with these guidelines, games should have clear goals, uncertain outcomes, feedback, and gradually increasing difficulty levels. Furthermore, they should contain curiosity and fantasy elements, such as emotional aspects. Moreover, they should respond in an appropriate way to the players’ actions, and they should provide them with choice over various environmental aspects (Malone, 1980).
Hays (2005) reports on these heuristics, and suggests a set of design recommendations for educational games, emphasizing on the instructional quality these games should have. More specifically, the game should be integrated into a larger educational program, and it should also incorporate elements that help students build new knowledge structures or complete their existing ones (Hays, 2005). Furthermore, as stated by Fisch (2005), the appropriate incorporation of educational content into the game is a key factor in the design of effective instructional games. Students should also be provided with offline material and resources that could add to the game’s educational value, as well as support and guidance by teachers and parents (Fisch, 2005). Prensky (2001), points out some features that engaging games have; these are the following: objectives, opposition, interaction, representation, and outcomes. Similarly, Kiili (2005) proposes an experiential gaming model based on Csikszentmihalyi’s flow theory and experiential learning principles; this model can be used for the design, analysis and evaluation of educational computer games. The above design guidelines and basic features of instructional games were taken into consideration in the design of the proposed game.

3.2 Development of the game

The final framework consists of the configurable online 2D game and its administration website, which was constructed in order to facilitate the (non-programmer) educator in the configuration of the game’s parameters. In accordance with the ADDIE model for Instructional Systems Design (ISD), the production of the framework comprised the following working phases: Analysis, Design, Development, Implementation, and Evaluation. Hence, a careful and thorough requirements analysis was deemed necessary, in order to determine the conditions that the particular instructional game should meet. The researchers were allowed to observe the educational process and the students’ performance during classes in a week’s time. Moreover, a semi-structured interview with two elementary school teachers was conducted, as well as a careful review of the relevant literature.

After careful consideration of the teachers’ recommendations, it was decided that they game should be simple, without any distracting material, and that it should not require any software installation. This way, it would be easier for teachers to use it in formal school settings. Concerning the difficulty level of the game’s questions, the educators suggested that it should increase as the game progresses. In addition, they stated that they would like to be able to change the game’s questions, according to the student’s knowledge and skills. Hence, a very important objective of this work was to create an adaptable game that could be reused in various educational settings and activities. It was also decided that the game should contain various mini challenges that the students could play in the limited time span of an individual class. That way, the game could be tailored to the level of the students, and it could also support different thematic units of the subject.

Afterwards, the game and its administration website were developed. More specifically, the game’s graphics and images were designed in Adobe Photoshop and Adobe Illustrator, and then the researchers proceeded with the development of the game’s prototype. Regarding the game development software, the game was created in Adobe Flash with the use of ActionScript, while the administration website was created using the PHP scripting language. The changeable content is saved in text files that were uploaded to the web server, and can be edited via the administration website. In accordance with the ADDIE model, the product of each working phase was subjected to formative evaluation and revisions. This way, it was confirmed that the initial criteria that had been set for the final product were met, and that any technical flaws were detected and corrected in time. Thus, the proper functioning of both the game and its administration website was ensured.

4. Description of the game

The game consists of nine challenges that the educator can fill up with questions, according to the course material. Since the game is addressed to elementary and secondary school students, attention was paid so that it is friendly and easy to use. An attempt was also made to incorporate most of the aforementioned characteristics of educational games into the proposed game. In this section, the main features of the game
are being presented, in connection with the proportionate characteristics that inspired the game design. Afterwards, there is a brief description of the configuration of the game through the administration website.

4.1 Story and characters

In accordance with Malone’s design heuristics (1980), one of the features that make games intrinsically motivating is the theme or fantasies that are incorporated. These two elements can elicit mental images of social situations or of physical objects to the players, rendering the game more interesting and engaging (Malone, 1980). Moreover, apart from being a source of motivation, the game’s narrative can be considered as a supportive factor that helps players make sense of the information they are presented with. Additionally, it can help students learn more efficiently, especially in case of difficult content (Waraich, 2004). For that reason, a theme and a story were added to the game. In the game’s story, three fictional friends, a boy, a girl, and a robot are vacationing on an exotic island, when the children’s uncle sends them a letter to warn them that the island’s volcano is going to erupt. The three friends face nine challenges in order to gather the necessary supplies and find a way to escape from the island. The player has to help them complete these challenges successfully. Each one of these challenges contains a variable number of questions on various algebraic and geometrical concepts. Special attention was paid so that the questions are well integrated into the game’s story. For example, in one instance of the game, the three friends visit the island’s store in order to buy supplies; the players have to buy the products with the most favorable prices after the discount, using their knowledge on solving equations with percentages. The players can read the game’s story and information about the three heroes of the game via the ‘Options’ menu of the game. Each of the game’s challenges is connected to the storyline of the game through its objectives and narrative. That way, the players can choose one challenge to play and do not need to play the whole game every time.

4.2 Goals and rules

Another important characteristic of compelling instructional games that was integrated into the particular game is the presence of clear rules and goals. More specifically, the players’ can choose from two different game modes: “Challenge game” and “Single game” mode. When playing in Challenge game mode, the players have to successfully complete the nine challenges of the game, while in Single game mode they can choose a challenge to play. The players have a one hundred seconds for each question, as well as five available lives (chances) for each challenge. They lose one life for every mistake they make. According to the rules of the game, when the players play in Single game mode and they lose, they can restart the same challenge or start another one. Otherwise, if they were playing in Challenge game mode, they have to start from the first challenge again.

4.3 Opposition elements

Furthermore, the game contains several elements of challenge and opposition, which, according to Prensky (2001), are problems the players are trying to solve. These elements make the game more engaging, however they should be equivalent to the player’s abilities (Prensky, 2001). In order to win the players have to complete successfully all the challenges of the game. However, the difficulty of the questions increases gradually, as the challenge progresses. Moreover, in the fourth challenge a different approach was followed; here, the difficulty of the questions increases with each correct answer, and decreases with each false one. Hence, the level of difficulty adapts to the player’s skills and level. As it has already been mentioned, the players have five lives for each of the game’s challenges at their disposal, and they lose a life each time they make a mistake. When they lose all of their lives, the game ends. Moreover, in accordance with Malone (1980), a score-keeping mechanism and a countdown timer were added, in order to create goals of different levels. The players have one hundred seconds to answer each question otherwise they lose. They also win points for each correct answer and lose points for each false one; answers to more difficult questions are rewarded with more points.
Each player’s high-score is saved and can be accessed through the ‘Options’ menu, so the players can compare their high-scores.

### 4.4 Interaction and feedback

According to Prensky (2001), engaging educational games should also contain interaction and feedback mechanisms that will help the player learn. Interaction can be either between the player and the computer, or between players (Prensky, 2001). The proposed game provides the players with immediate feedback messages, in order to help them understand and correct their mistakes. Moreover, directions and help messages appear in each of the game’s challenges, so that they players understand how the game works and learn to navigate through it. The players can also view their high-scores, and configure some of the game’s parameters, such as the game’s sounds, through the “Options” menu. Additionally, they can communicate with the authors and creators of the game via a web form, in order to send their suggestions and comments (Figure 2). The players can interact with various elements of the game; however, the game did not support interaction between the players by the time it was evaluated.

![Various screens of the game.](image)

**Figure 2:** Various screens of the game.

### 4.5 Configuration options

As it has already been mentioned, one of the main purposes of this work was the development of an easily configurable online game. The whole framework that was created consists of the online game and its administration website. Using this administration website, the educator can change the following: (a) the total number of each challenge’s questions, (b) the content of each question and its corresponding answer, (c) the instructions and help messages for each challenge, and (d) the images that appear in the game, as well as the images of the help messages. Moreover, in the fourth challenge the educator can add a set of more difficult questions that will be used when the player answers correctly, in order to increase the level of the questions’ difficulty. The configuration process is the following: the educators should login to the administration website and then select and edit the game’s messages, directions, questions and answers. They can also delete questions and answers, or add new ones, and furthermore, they can upload new images or delete the existing ones (Figure 3). Finally, they should save their changes in order for them to appear in the game.
5. Evaluation of the game’s prototype

5.1 Description of the evaluation activities

An important objective of this study was the evaluation of the game as to its usability, capabilities and perceived usefulness, in order to improve it in subsequent editions. For that reason, several educational activities, which served as a means to gather qualitative data, were organised and implemented. Hence, the researchers had the opportunity to observe the students’ reaction to the game, and to ask them for their feedback. Additionally, in order to gather quantitative data, a pilot study with twelve (12) 6th grade students of a private school was conducted. The group of students consisted of eight (8) girls and four (4) boys of various nationalities, aged 10-12 years old.

The pilot study comprised two different educational activities conducted in the computer laboratory of the school. Each one lasted about 45 two differ

The questionnaire for this study included 18 questions focused on the game in the computer laboratory of the school) boys of various nationalities, aged 10-12 years old. tions. For that reasonere 1 was assigned to ‘strongly disagree’ and 5 to ‘strongly agree’. Regarding the game’s content, each challenge was enriched with new questions on arithmetic and geometrical concepts, in accordance with the material taught in the classroom. The evaluation data also included the researchers’ notes and observations from the educational activities. The results were quite encouraging; however, they could not be generalized, due to the limited number of the participants and that of the educational activities.
For that reason, a second evaluation experiment that lasted 14 weeks was also conducted. The participants of this study were 37 randomly selected students from a typical public secondary school, consisting of 23 boys and 14 girls aged 12-14 years old. The students agreed voluntarily to participate in the experiment by interacting with the game daily and individually. Responsible for supporting them during the whole intervention was primarily their teacher. Before the intervention could begin, the cooperating teacher organised an introductory session, where the researchers presented the game to the students. Moreover, the teacher informed the students’ parents about the intervention and they signed the necessary parent consent forms.

For the purpose of this evaluation a new, more complete, paper-based questionnaire was constructed. The particular questionnaire, which elicited both qualitative and quantitative data, was based on the Questionnaire for User Interface Satisfaction (QUIS) (Chin, Diehl and Norman, 1988), and on Lund’s USE Questionnaire (USE) (2001). The 22 questions that were included in the questionnaire corresponded to the following eight dimensions: perceived usefulness, ease of use, ease of learning, satisfaction, screen, terminology and system information, system capabilities, and overall reaction to the software. The questions’ type was five-point Likert scale, as before. Additionally, the questionnaire included two open-ended questions about the best and worst aspects of the game.

The participants played the game from home daily during the 14 weeks of the intervention. The teacher was able to check their involvement, as all participants had personal accounts. Every week, the teacher updated the game’s challenges with new questions based on what was taught in the lessons. Moreover, every two weeks a debriefing session was conducted in the school computer laboratory. At the end of the intervention, the students completed the anonymous questionnaire. In the next section, the results of the analysis of the questionnaire are being analytically presented.

5.2 Results

The students’ answers to the Likert type questions of the questionnaire were analyzed by descriptive statistics, and their answers to the open-ended questions were grouped according to their common themes. The statistical analyses were performed using the SPSS 20 statistical package, with the level of significance set to 0.05. The game’s usability was assessed using the students’ performance in each dimension. This was calculated using the mean score of their answers to the corresponding questions (Boone and Boone, 2012). Generally, as the results indicated, the students’ opinion about the game’s usability was moderate to good. In particular, regarding the game’s ease of learning, the statistical results are the following: M = 3.77, SD = 1.07, N = 37. The students’ static concerning the game’s terminological and system information are also positive, as the statistical results are M = 3.67, SD = 0.84, N = 37, and M = 3.63, SD = 0.77, N = 37, respectively. Furthermore, their responses to the rest of the questionnaire’s dimensions were all above average, while the mean score for the students score est of the questionnaire= 37, and M = 3.63, SD = 0.770.96, N = 37). However, the lowest score was observed in the dimension concerning the system capabilities (M = 3.33, SD = 0.98, N =37).

In addition, according to the students’ answers to the open-ended questions, the game: (a) helped them understand the lesson, as well as some difficult mathematical concepts better; (b) it is easy, entertaining and pleasant; (c) it helps apply a more innovative approach to the learning process; and (d) it is flexible and, thus, it can constitute a useful tool for the revision of the lesson taught. Thus, concerning the first research question (What is the students’ opinion regarding the usability of the ‘Volcanic Riddles’ game?), it was deduced that the students were quite positive.

However, some students encountered minor problems regarding the use of the game. For example, five students stated in their comments that they would prefer the game to be in the Greek language, instead of English. Other observations were that it is quite simple, and it does not provide enough explanations on some
solutions. Their opinion can also be justified by the fact that they mostly played the game from home, without the aid of their teacher. It should be noted that the student’s responses to the related questions during the pilot study were a lot more positive. For instance, regarding the game were a lot more positive. The pilot studies that it was very easy to understand how the game is played, while two pupils were neutral (M=4.67, SD=0.778, N=12). Also, seven pupils strongly agreed and three pupils agreed that the game did not require any complex computer usage, whereas two pupils were neutral (M=4.42, SD=0.793, N=12). Eight pupils strongly agreed and three pupils agreed that the game could help them improve their skills, whereas one pupil was neutral (M=4.58, SD=0.669, N=12). The students game were a lot more positive. pilot studydata that it was very easy to understand how the game is played, while two pupils were neutral (M=4.67, SD=0.778, N=12). Eight pupils strongly agreed and three pupils agreed that the game could help them improve their skills, whereas one pupil was neutral (M=4.58, SD=0.669, N=12). The students game were a lot more positive. pilot study that it was very easy to understand how the game is played, while two pupils were neutral (M=4.67, SD=0.778, N=12). Eight pupils strongly agreed and three pupils agreed that the game could help them improve their skills, whereas one pupil was neutral (M=4.58, SD=0.669, N=12). The students game were a lot more positive. pilot studyucture, functions, and motivational appeal were also quite positive. However, only three students strongly agreed that they use the game’s “Help” option, whereas two students agreed and seven students strongly disagreed (M=2.50, SD=1.88, N=12). Indeed, the students preferred to ask the teacher and the researchers when they did not know or understand something in the game.

These results can be explained on the premise that the pilot study included a small number of activities (2), while in the longterm intervention the students had 14 weeks to explore the game. Moreover, in the pilot study, the activities took place during class with the assistance of the teacher, and in the form of a pleasant break, while in the longterm experiment the students would log in from their homes and in their free time, in order to play the game. Lastly, concerning both teachers’ opinion about the game and its administration website, it was quite positive, as they considered them to be friendly and easy-to-use. Hence, regarding the second research question (In what educational context could this game be used by educators?), it was concluded that the game could actually be used as a useful educational tool for classroom activities. Moreover, with some improvements and extensions, it could also be used in distance-learning scenarios. Additionally, it became apparent that, in accordance with Hays (2005), the educator’s feedback and the debriefing sessions are very important for the support and guidance of the students.

Additionally, a third research question (Will the gender or grade of students affect their opinion about the usability of the ‘Volcanic Riddles’ game?) was also investigated in this evaluation study. Firstly, it was examined whether the students’ opinion for the game differs based on gender. After some preliminary tests were conducted on the data, it was decided to use the Mann-Whitney U Test, since it can be used when the variables are not necessarily normally distributed. According to the results, it can be presumed that there were no significant differences between boys’ and girls’ opinions regarding the game, based on the scores for the eight dimensions. Nevertheless, when examining each one of the 22 questions, it became apparent that the girls learned to use the game more quickly ($Mdn=5$), than the boys ($Mdn=3$), $U=90.5, p=.22, r=.37$. However, the boys considered the game to be more satisfactory ($Mdn=4$), than the girls ($Mdn=3$), $U=100, p=.49, r=.32$.

Lastly, the students were divided into three independent groups, according to their age and grade. Thus, the first group consisted of 12 1st grade students, the second group of 13 2nd grade students, and third group of 12 3rd grade students. A Kruskal-Wallis test was then applied to evaluate differences among the three grade conditions. The results of the analysis indicated a significant effect of grade ($\chi^2 (2, N=37) = 6.74, p = .34$) only on the students’ opinion about the consistency of terms that were used throughout the game. Indeed, the follow-up tests that were conducted to evaluate pairwise differences among the three groups revealed that the 3rd grade students did not consider the use of terms to be consistent. In particular, a post-hoc test using Mann-Whitney tests with Bonferroni correction showed significant differences between group 1 and 3 ($p = .18, r = .38$), and between group 2 and 3 ($p = .42, r = .33$). However, there were no significant differences according to the students’ grade on any other questions or the eight dimensions of the questionnaire.

6. Discussion and conclusions

This paper presented the design and development of the prototype of a configurable online 2D game, aimed at assisting the educator in the teaching of primary and secondary school Mathematics. Furthermore, the
Prototype was evaluated through a pilot study and a long-term intervention in real school settings, in order to assess its usability aspects and to find any possible flaws. According to the results of the two evaluation studies, the students’ opinions about the game were mostly positive, and they considered it to be a useful and engaging learning tool, regardless of age and gender. Furthermore, concerning the game’s usability, most of its features elicited average to positive responses from the students and the educators alike. Moreover, the educators encountered no difficulties in configuring the game, and the planned educational activities were concluded successfully. Thus, it was deduced that the particular game could actually be successfully incorporated and used by educators as a supplementary tool for the teaching of formal curricular material.

These findings are encouraging and suggest that game-based learning activities are well-accepted and appreciated by students. Furthermore, the great importance of the educator’s feedback and guidance on how to use the game became apparent, in accordance with Hays (2005) and Fisch (2005). The work presented in this paper had certain limitations; for instance, the game is addressed to younger ages and has a short storyline and a limited number of challenges and functions. Additionally, the aforementioned evaluation studies focused only on the game’s usability, as the researchers’ intention was to elicit students’ responses to this game prototype. Our future work aims at improving and extending the game, by adding new features, more hints and help messages, and a longer storyline. Moreover, a multi-player feature should be added to the game, in order to assess its impact on student’s opinion about the game. Also, it would be worth investigating whether cooperative or competitive game playing can enhance students’ engagement and motivation. Lastly, further research should be conducted in order to examine how the educator’s material could be more efficiently integrated into the game’s storyline and narrative.

The contribution of this paper is that it described a concrete case study on the creation and evaluation of an educational game designed according to instructional game design principles. In more detail, the game included interaction and feedback elements, a background story, clear rules, objectives and outcomes, combined with educational aspects. As it became apparent through the evaluation process, such a game can be easily integrated into the classroom to support the teaching of formal curricular material. Moreover, it can be used for distance learning, if certain extensions are considered. Finally, this paper demonstrated that it is possible to create a functional prototype of an online game that can be adapted according to the educator’s specific needs. In conclusion, it is hoped that this study adds to the existing research on instructional games and that the presented game will eventually become an effective educational tool.

References


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Content and Language Integrated Learning through an online Game in Primary School: A case study

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Abstract: In this paper an educational design proposal is presented which combines two well established teaching approaches, that of Game-based Learning (GBL) and Content and Language Integrated Learning (CLIL). The context of the proposal was the design of an educational geography computer game, utilizing QR Codes and Google Earth for teaching English Language to Greek Primary School students. This integration provides a motivational and cognitive basis for language learning, since it represents a meaningful, contextualized activity and on the other hand, gives students the chance to expand their cognitive skills and use more sophisticated language. The proposed game immersed 11 to 12-year-old students in problem solving challenges regarding the use of geography in realistic contexts. While attempting to solve these problems, students were engaged in eight-week collaborative work, involving six levels of gameplay by following hints, provided by QR codes images. The findings of this case study suggest how foreign language learning can successfully take place within a geography game-based learning environment, and they underscore the efficacy of approaching GBL in terms of performance. Students' performance was evaluated through knowledge tests and various complex tasks throughout the game play, involving writing and reading skills. In general, students showed positive attitudes towards the game and the post-test results have significant differences compared to those of the pre-test, in terms of vocabulary acquisition and reading skills in the foreign language and geography knowledge. The results also showed that the collaboration required by this game, allowed the students to interact in a controlled environment, where they undertook roles and responsibilities. To this end, the findings will make an important contribution to the empirical evidence of GBL particularly with regards to its application in primary education.

Keywords: QR Codes, Google Earth, CLIL, Language learning, GBL

1. Introduction

The present case study is a follow up of a previous research proposal, in which an idea of combining the educational approaches of GBL and CLIL as a basis for foreign language learning was described (Dourda et al, 2012). GBL, which supports and facilitates the learning process in a more comfortable environment, and CLIL, which is believed to help students improve specific language terminology by centering on meaning, were effectively implemented in the context of the present case study (Anderson et al, 2008; Dalton-Puffer and Smit, 2007). In this paper, the results of the study on language learning aspects such as vocabulary and reading skills as well as the learning strategies, followed by the students, are presented. In addition, content knowledge and collaboration also move into focus.

The main focus of the study was English as a foreign Language (EFL) Teaching, through an interdisciplinary approach which involves gaming, geography, problem solving and critical thinking. A detective game was designed and utilized as means of introducing geography related content in order to provide hints for the detection of a criminal. The case study was conducted with the participation of 17 students from a public primary school, in Greece. Thus, 11 to 12-year-old students were introduced to geographical information, as well as to post task activities, in a foreign language, while attempting to solve a mystery, by combining data within a game context. The aim of the study was to explore the teaching potential deriving from the combination of GBL and CLIL approaches in order to produce an authentic, meaningful and enjoyable learning context.
The paper is structured as follows; initially the theoretical background is presented, discussing the GBL and CLIL teaching approaches within the Foreign Language teaching context. Then, the research methodology and results are presented, before the concluding discussion.

2. Theoretical Background

2.1 GBL in Foreign Language (FL) Learning context

As researchers have continuously urged foreign language educators to seek alternatives to traditional instruction, during the last decade the GBL educational approach keeps increasing in the foreign language learning context, utilizing the ability of games to make language education entertaining and to provide learning environments that contextualize knowledge and immersive experiences for learners (Anderson et al, 2008; Meyer, 2009).

GBL, which is used to describe the application of games in learning, provides approaches that better corresponds to students’ requirements or habits and, as a consequence, actively engage students in the learning process (Smith and Mann, 2002; Gee, 2003). GBL in particular embodies the philosophy of ‘learning through a grammar of doing and being’ and provides students with opportunities for authentic learning (Squire, 2006). Through various kinds of software, GBL assists students in language learning, while developing their problem solving and critical thinking skills through engagement and iterative feedback that are crucial to the learning process (Donmus, 2010). In addition, GBL approach to foreign language learning provides more effective learning compared to traditional methods, develops positive attitudes in students and increases the retention process (Donmus, 2010).

Computer games are effective because learning is not only relevant but also applied and practiced within a meaningful context, where students are encouraged to combine knowledge from different areas in order to choose a solution or to make a decision at a certain point (Van Eck, 2006). Thus, computer games can be used to easily learn a particular content and can be useful instruments for learning specific strategies (Gros, 2007). Moreover, the adaptive qualities of most games ensure that “learners are motivated to persist in their learning, thus increasing the chance of further exposure to target language input, and opportunities for output” (Reinders, 2012).

GBL also provides the opportunity for Content-based Learning (CBL), as “games are not necessarily about memorizing or providing correct answers”, but rather about the comprehension of the content provided in the game and the application of various learning strategies (Sørensen and Meyer, 2007: 561). Furthermore, Sørensen and Meyer (2007: 561) add that the role of GBL in foreign language learning “has been moving away from an association with drills, grammatical explanations and translation tests, into more communicative based contexts where task-based, project-based and content-based approaches are integrated”.

Finally, in a number of studies that focused on the retention of learning and students' preference, results were better when using the GBL approach (Pivec and Dziabenko, 2004). However, other studies exist in which the results are not so clearly in favor of GBL, as it is not a flawless learning method per se (Pivec and Dziabenko, 2004). Although engagement and motivation are significant advantages of GBL, they are not enough for educational purposes. The design of the learning environment is a crucial factor for improving learning, considering that a well-designed game is user-centered and promotes students’ social and cognitive development (Gros, 2007).

2.2 Content and Language Integrated Learning (CLIL) in FL Context

As European educational systems are making great efforts to improve students’ competence in foreign languages, a different approach, described with the term CLIL, is gaining importance and becoming a well-established teaching method all over Europe (Järvinen, 2007). According to Eurydice (2006: 8) the acronym
CLIL is used to describe that school situation whereby “a foreign language is the vehicle to teach certain subjects in the curriculum other than the language lessons themselves”.

The CLIL approach serves as a tool for the promotion of the foreign language teaching and has been praised on many different grounds. First of all, the primacy of meaning over form is considered to have positive effects on the affective dimension, reducing target language anxiety and increasing interest and motivation in the learners (Dalton-Puffer and Smit, 2007). Secondly, it is thought that CLIL is effective, because by being able to comprehend and reason about a content in a foreign language, students have the chance to improve themselves in specific language terminology and generally to expand their cognitive skills (Lasagabaster, 2008). Furthermore, learning about geography, science or history in the CLIL classroom gives the use of the foreign language a purpose and a kind of meaningfulness that is believed to be absent from typical language instruction (Dalton-Puffer and Smit, 2007). This may happen because it provides students with repeated, natural exposure to the language which mirrors the environment of first language acquisition (Troncale, 2002). As a result, learning a foreign language through content provides an opportunity to teach academic tasks and higher order thinking skills which is not only beneficial for foreign language students, but also necessary for their overall success in school (Troncale, 2002).

It appears that certain language competence aspects benefit more from the CLIL method. More specifically, receptive skills, lexicon, fluency and affective outcomes gain most from this method. On the side of the productive skills, it can be said with regard to speaking that CLIL students often display greater fluency, quantity and creativity and show the kind of higher risk-taking inclination often associated with good language learners (Dalton-Puffer, 2002). Positive affective outcomes of CLIL are also observed, while after a certain amount of time spent in CLIL lessons the learners seem to lose their inhibitions to use the foreign language spontaneously for face-to-face interaction (Dalton-Puffer, 2002).

What is at issue in this paper is clearly the role of reading and lexicon in language teaching, which seem to benefit more from the CLIL approach. Tsai and Shang (2010) have shown that utilizing CLIL instruction enhances students’ reading comprehension as well as critical thinking ability. The greatest gain in terms of the language system, however, is undoubtedly produced in the lexicon, as through studying content subjects in the foreign language CLIL learners obtain larger vocabularies of subject-specific terms (Dalton-Puffer, 2002).

2.3 Foreign Language Learning Strategies

Although many students are successful in learning a foreign language regardless the teaching method, it is argued that a wrong combination between the learning style of a student and the teaching style of educator can lead to stress and frustration and not to the achievement of the learning objectives (Bull and Ma, 2001). In order for the students to be more autonomous and the learning outcomes to get improved, it is necessary to examine the use of language learning strategies (Bull and Ma, 2001).

O’Malley and Chamot (1990), define learning strategies as the special thoughts or behaviors that individuals use to help comprehend, learn, or retain new information. For them, learning strategies are important to language learning because they enhance students’ own learning. A similar definition is also given by Scarcella and Oxford (1992: 63), defining the learning strategies as "specific actions, behaviours, steps, or techniques - such as seeking interlocutors, or giving to yourself the incentive to deal with a difficult language task - used by students to enhance their own learning".

It is believed by many in the field of education that the effective use of learning strategies is one of the most important skills that students must acquire in order to succeed in language learning (Gallo-Crail and Zerwekh, 2002). When a student deliberately chooses the strategies that match his/her own way of learning, these strategies become a useful tool for active, conscious, and purposeful self-regulation of learning.

The learning strategies are important to foreign language learning because they enhance the students’ own learning, and students use them for active, self-regulated involvement that is important for the development
of communication skills (Oxford, 1990). According to Oxford (2003) learning strategies can be classified into six groups: cognitive, metacognitive, memory-related, compensatory, affective, and social. The main focus of the present case study is on the cognitive strategies (which relate to how students think about their learning and enable them to manipulate the language material in direct ways), the memory-related strategies (which relate to how students remember language), the social strategies (which involve learning by interaction with others) and compensatory strategies (which enable students to make up for limited knowledge).

Moreover, both reading and vocabulary are considered to be fundamental to foreign language competence and often constitute the greatest difficulty for learners. This study aims at examining their use of reading and vocabulary learning strategies (and whether an optimum way to deploy learning strategy training exists). With a special focus on a hypertext approach to foreign language reading, content knowledge can be acquired gradually and incrementally through repeated exposures to the various tasks in the game context. This can lead to richer content-specific vocabulary use (efficiency that can be achieved by simultaneous twofold learning-reading and vocabulary), and the more learner-based nature of the foreign language acquisition. For instance, by exposing learners to an amount of unknown geography-related vocabulary, the aim is to attempt to enhance the strategy of inferring word meaning from context, which seems to be ineffectively used by the learners. Besides, Coady (1993) emphasizes the importance of vocabulary building as an integral part of reading, viewing it as a strategic skill, necessary to be included in reading instruction (in Kusumarasdyati, 2006).

3. Case Study

As the new generations are introduced into a digital world, also through computer games, the ways of interaction with the technology change the ways of learning and the production of knowledge. Therefore the main focus of the present study is to explore new teaching methods, in order to enhance the skills needed for the future citizens in a digital society. Furthermore, this could serve as a paradigm of utilizing the children’s familiarity with digital technologies, following Prensky's (2001) characterization of them as “digital natives”.

Despite the fact that more and more teachers today use computer games as tools for foreign language teaching, the way that learning takes place in the classroom in such an environment has not been sufficiently studied. The present study has exactly this purpose that is to explore ways in which the learning takes place within a system where a computer game has the role of the educational material. More specifically, the purpose of the current case study was to improve sixth-grade primary school students’ geographical knowledge and English vocabulary through a combination of GBL and CLIL settings. Moreover, an attempt was made to enhance and identify the learning strategies that students use while learning a foreign language, since their effective use is believed to be “one of the most important skills that students need to master in order to achieve success in language learning” (Gallo-Crail & Zerwekh, 2002: 57).

Taking into account the aforementioned theoretical grounds, a game combining the benefits of GBL and the CLIL methodology was designed, in order to create a learning environment for acquiring geography-related content, using the English language as a medium. The totality of the game-play involved interacting directly with language, mostly through reading and writing. The expected outcome of this case study was for the students to develop the ability to identify information in order to solve a problem, identify resources to be used for gathering information (provided by the QR Codes), make decisions, analyze and present solutions in a written form. Students were also encouraged to engage positively in the learning process by directing their own learning, by being active, reflective and critical learners, by extending learning beyond the presented situation into new areas whereby some transfer of skills, abilities, knowledge and strategies may take place.

3.1 Game Description

This section of the paper focuses entirely on a more thorough description of the game itself, as the didactical concepts, the design principles and the game’s technological platform have already been analyzed (Dourda et al, 2012).
“Whodunit” (for "Who done [did] it?") is a plot-driven, web-based detective game, suitable for 11-12 years old students. The game is structured around six stations/levels (landmarks around the globe) in the form of missions, which comprise hypermedia learning material and relevant questions of progressive difficulty levels. In each mission, the students have to solve a number of problems, presented to them as open-ended questions. The learning material encompasses websites with texts and images, relevant to both geography and a detective story. To successfully complete the game, students have to accomplish all six missions and to collect all clues that the suspect leaves behind. They are initially placed in their hometown (realistic context), where they undertake the role of a detective, following the traces of a notorious criminal, Mr. X. Within each level, the detective should correctly answer all the questions - sent to the Chief's e-mail or written on paper - posed to them, gaining the corresponding points in order to obtain a special key, granting them the right to proceed to the next level. The final goal is gather all the clues and the necessary information about Mr. X’s identity, thus arresting him by travelling at the location he is hiding in. The character design and narrative environments of the game were constructed in such a way as to foster students’ intrinsic motivation and sustain their persistent participation in the game playing process.

The game is entirely web-based and consists of three different sites – the Diary, the Chief’s office and the Internet. The Diary is the place where the detective writes information about Mr. X’s moves, gathers important evidence about his identity and describes the geographical location and the natives that inhabit this location (Figure 1).

![Figure 1: Screenshot: Detective’s Diary – Investigation in the Amazon Rainforest](image)

The Chief’s office is the place where the detective informs the Chief via letters, e-mails, telegrams, post cards etc. about Mr. X’s whereabouts, provides the evidence gathered and the clue for the next location to be investigated (Figure 2).
Figure 2: Screenshot: Chief’s Office – Letter to the Chief

The Internet refers to the site where the detective searches for information about the geographical location he/she is going to travel next (Figure 3). Each time the students investigate a specific location, they take the opportunity to refine their search by gathering information about the geographical position, the climate, the local people as well as the flora and fauna of each location.

Figure 3: Screenshot: Internet – Information about the Sahara Desert

The main goal of the game is to follow the track of Mr. X around the world, provided by clues hidden in QR Codes. This allows the students to “travel”, visiting famous geographical sites/locations and world attractions: the Sahara Desert, the Amazon Rainforest, the Grand Canyon, the Great Barrier Reef, the Himalayas and the Caspian Sea (Figure 4).
The location clue discloses the whereabouts of Mr. X, implying his next trace around the world. When the information is clear to the students, they can search the location on Google Earth and find the pinned QR Code that leads them to the appropriate website with further information. However, if the information is indirect and the students are unable to recognize their next destination, the QR-Code hints help them find the precise location.

In the various locations, students need to conduct some detective work in order to unveil the trace of Mr. X. Through investigating each location and with the help of the natives, important information is collected and listed in the clue log (Diary). The narrative frame of the game invites engages the students in a challenging, English speaking world. In this sense, English is learned through a way that is not unfamiliar to the students, but allows them to participate on a confident basis in the game. As described in section 2.2, by conducting all the prescribed activity in the foreign language, students are able to obtain larger vocabularies of subject-specific terms display “greater fluency, quantity and creativity and show the kind of higher risk-taking inclination often associated with good language learners” (Dalton-Puffer, 2002). The game provides a familiar and motivating context for the learning activity.

Moreover, students can visit their journals, created for the game, to check and review the cases and the various evidences. By writing in a journal students will be able to assess their own activities, to see how they are doing and to evaluate their decisions and actions (metacognitive awareness) (Figure 5). Students/players level up by solving the mystery cases, investigating more clues, and hunting for Mr. X around the world. Additional rewards will be offered after accomplishing various tasks.
3.2 Research Methodology

The presented case study immersed seventeen (17) students (9 girls and 8 boys) from 11 to 12 years old attending a Greek Public Primary School of Thessaloniki in problem solving challenges. Students, who were chosen randomly, were engaged in eight-week collaborative work (5th February, 2013 – 29th March, 2013), involving six levels of gameplay.

First a survey of both students’ digital habits and learning preferences was conducted to establish a contextual baseline on which to place the study. The survey indicated that all the students were computer proficient and frequent users of computer games. Moreover, for the purposes of the study a knowledge test - consisted of 30 true/false (e.g. “The Sahara Desert is in Asia”) or multiple-choice (e.g. “Which river runs through the Grand Canyon?”) questions to measure students’ performance in geography and English vocabulary - was conducted by the researcher according to the requirements of the educational game. The knowledge test was completed twice, once before the implementation of the game and once after it had been completed. The researcher used the same pre- and post-tests to ensure the reliability of the test in terms of format, content and cognitive levels. After the implementation of the game, a satisfaction/feedback questionnaire was also distributed to the participants. The questionnaire included nineteen (19) Likert scale questions and three (3) open questions, in order to investigate the extent of students’ satisfaction with the game, their overall views of the application and any proposals for improvement.

After the pre-test, the researcher introduced the game to the students and asked them to form groups of three (one team only consisted of two members). Each team member undertook a role, such as the manager, the computer user, and the journal keeper. The students were informed that the game process involved 45 minutes of instruction and one hour of playing. Instruction consisted of multimedia presentations (Prezi), in order for them to be introduced to each game level’s content and familiarized with the relevant geographical knowledge and unknown English vocabulary, necessary for them to proceed with the game. The instructive session was implemented in a game-like format that seemed to motivate the students. After each instruction, students accessed the game online in the school computer laboratory.
By completing each game level, the students were asked to respond to various complex tasks whose purpose was to assess and evaluate their content and language knowledge. Students’ evaluation began after each game session, including a variety of complex tasks that emerged students to write (on paper or online) e-mails/letters and conduct reports, describing their experience from each mission around the world, either by the detective’s or the indigenous inhabitant’s perspective. Other tasks also required from the students to record a video of themselves talking in English about their progress in the game, and even communicate through a message application on a mobile phone with the Chief (Figure 6). In that way, it was possible to obtain immediate data about their performance in Geography, their improvement in English vocabulary as well as reading and writing skills and, moreover, the various language learning strategies they used.

![Figure 6: Screenshot: An example of a post task (evaluation)](image)

### 3.3 Research Hypothesis

The research hypothesis is that the implementation of such a teaching approach will have the following beneficial influences on the students’: (a) geography knowledge, (b) English vocabulary, (c) reading skills, (d) the use of foreign language learning strategies, (e) collaboration, (f) satisfaction with the game.

### 4. Results

In this part of the paper the data collected throughout the case study are presented. The processing and analysis of data has helped to provide answers to the research questions raised above.

Through the game the playing process became a “serious” activity and the students achieved both the game and the learning objectives. The results are based both on acquired quantitative and qualitative data. Student’s familiarity with the computer (games), their satisfaction with the game and their language learning preferences were collected through questionnaires (quantitative data). To export results with regard to the content of geography and the vocabulary in the English language the two cognitive tests were compared (pre-and post-test), as well as the writings of pupils’ journal and the game logs (quantitative data). As far as the pupils’ reading skills are concerned the game logs and, in particular, the observations were taken into consideration (qualitative data). Finally, student’s use of learning strategies was obtained through observation, the researcher’s and students’ journal, video recording as well as through the various tasks the students achieved after each gameplay (qualitative data).

### 4.1 Student Learning Outcome

The first research question examined the difference of students’ performance in the pre- and post-test in terms of content knowledge. Via the educational game, the students appeared to be led effortlessly to
knowledge, giving particular emphasis on the geographical content which they considered to be an essential and integral part of the game. Comparing the two cognitive tests (pre- and post-test), results show that students’ content knowledge was considerably improved. All students without exception showed higher scores in the second test (post-test) as compared with the first one (pre-test) (Figure 7). More specifically, the average percentage of students’ positive progress in the knowledge tests was approximately 30%. No significant difference was found among the participants, in correlation with their familiarity with computers, as they were all computer proficient.

Figure 7: Total Correct Answers per Student in pre- and post-test

Moreover, it was observed that during the completion of post-test, none of the students made any certain clarifying questions regarding to the content of the cognitive test. Additionally, none of the students responded at random to any of the questions appeared in the test, which can be seen by comparing the total number of correct answers (Figure 8).

Figure 8: Students’ (Ss) Total Correct Answers in pre- and post-test

As far as the second research question is concerned, qualitative data obtained through observation, journals, video-recording and evaluation tasks, showed that students’ vocabulary was improved. Analysing the texts in their journals and the various post-task and gaming activities, it became clear that the children used an abundance of new and difficult words in the English language (Figure 9). The researcher also noted the fact that students completed the post-test without asking for help in order to understand the meaning of some
questions or answers, as opposed to the pre-test, where they faced difficulties due to the number of unknown words.

![Vocabulary Learning](image)

**Figure 9: Students’ vocabulary use throughout the game**

It also needs to be highlighted that the students spelled correctly the various words they had learned when they wanted to produce written texts, which indicates an efficient way of learning vocabulary.

It is also worth mentioning that throughout the game and the post-stage, the students faced the various tasks as if there were a part of the game instead of an additional work for their English language subject, without even having the fear of making an error. Consequently, they did not connect the various activities with the traditional way of learning a foreign language, and as a result they let their imagination free and produced authentic texts by using words they met or they had already known. In addition, it was noteworthy the fact that the students in their efforts to gain a higher score in the game and acquire the key for the next level, were trying to use the words they encountered in the various texts, and especially the difficult ones. In consequence the game provided the students with the motives to learn on their own, without being asked directly, new and specialized vocabulary in the English language.

As far as the students’ reading skills are concerned, data was collected mainly through observation, with the help of video recording and the researcher’s journal. Results showed that through the continuous exposure to the texts of the game students’ reading skills – improved considerably. While in the beginning of the game most students were facing difficulties in reading comprehension and preferred a more hasty and careless reading, in the course of the game they appeared to understand the texts to a large extent. In an extent, this is due to the students’ continuous exposure to English language texts throughout the game, which they had to comprehend in order to provide answers to the various questions and proceed in the game.

It is also worth pointing out the various reading strategies the students used during the game. The use of the reading strategies was enhanced, as it became apparent a considerable difference between the first (1<sup>st</sup>) and the sixth (6<sup>th</sup>) level of the game (Figure 10). Initially, an increase in the students’ use of memory strategies, was observed. More specifically, in the first (1<sup>st</sup>) level of the game five (5) out of the seventeen (17) students created mental linkages by trying to associate the new information with another one or with concepts they already knew. On the contrary, in the sixth (6<sup>th</sup>) level of the game the students’ percent that made use of this specific strategy was increased to 65 (%). Similarly, it was noted an increase of 36% in the number of students that used imagery by trying to correlate the images with the words found in the various texts, in order to understand them better.
In addition, it is interesting to note that students used widely some of the cognitive strategies while reading the texts in the game. Specifically, the percent of students that used repetition while reading, was decreased in the sixth level to 18%. It is likely that this occurred because, although in the beginning students read the texts more than once in order to comprehend them, at the end of the game comprehension seemed a lot easier, probably due to the less unknown words. A decrease of 41% was observed during analysing and reasoning, as some of the students in the sixth level stopped using the translation and transfer of knowledge and structures from their mother tongue in order to understand and produce an expression in the foreign language. This result is encouraging, as it reveals the familiarization of students with the English language structures, without the need of connection with those of their mother tongue.

Finally, an important increase (50%) was observed in the percent of students that used the strategies of skimming and scanning in order to understand the basic idea of the texts and to detect important information. More specifically, although in the first level of the game only 7 out of 17 students seemed to master these strategies, in the last level of the game 14 students started scanning for information, inferring word meaning from the context and as they progressed in the game they overcame any hindrance in the form of unfamiliar words.

4.2 Student Language Learning Strategies

The study also focused on identifying the learning strategies used during unintentional vocabulary learning. Moreover an attempt was made to assess the relationship between strategy use and vocabulary performance. As far as vocabulary learning is concerned, results indicate that certain learning strategies are more effective in acquiring new vocabulary words and that students have preferences in the strategies they use to learn these words in the foreign language (Figure 11). Data was collected through questionnaires, video-recordings and the researcher’s journal.

More specifically, 65% of the students (11 out of 17 students) preferred and used the memory strategies throughout the game. Students tended to retrieve information and understand unknown vocabulary via creating mental linkages, associating unknown with known words and using their imagination. For example, most students that recognized a familiar word in the foreign language, tried to simulate its sound with that of their mother tongue.

Cognitive strategies were used by the 76% of the students (13 out of 17 students), and mainly by skimming and scanning in order to find information in the texts and translating them into their mother tongue. During the learning of new vocabulary, 3 out of 6 teams made use of resources for receiving and sending messages, such
as search engines (e.g. Google) and online dictionaries. Another cognitive strategy used by all teams in the study and found mainly in the written texts, was the recombination of already known words in order to form larger and more complex sentences. Finally, all six teams kept notes in their journal not only during the instruction stage but even during the gameplay, and as a result the learning of new vocabulary was enhanced. It is worth mentioning the fact that the teams that kept more notes and continuously updated their journal were those that displayed higher motivation in the game.

![Learning Strategies](image)

**Figure 11:** The language learning strategies students used in the study

Social strategies were preferred by the 82% of the students (14 out of 17 students), as most of them were motivated to cooperate with their peers in order to achieve a common goal in completing the game successfully. They were also often asking questions for clarification or even correction both to their peers and the researcher.

Compensation strategies, which were mainly noted in the researcher’s journal and video recordings, were widely used by all the students in order to overcome their limited knowledge in English. In particular, 10 out of 17 students preferred to use gestures or facial expressions so that they could communicate with the members of their team or with the researcher. The creation of a new word (coining words) occupied the 11% of the compensatory strategies used by the students, while the use of a circumlocution or a synonym was at 19%. Moreover, 12 out of 17 students were using clues in order to guess the meaning of what they were reading. It is notable that all 17 students were frequently asking for help either by their peers or the researcher, as well as often switching to their mother tongue.

### 4.3 Student Collaboration

Allowing students to collaborate with peers is another issue, explored in this study. As students worked in groups, they were actively responsible for their own learning processes. Information retrieved from observation, the researcher’s journal and video-recordings showed that students engaged in collaborative learning, enhanced problem solving skills and critical thinking, they learned to work in a group and became autonomous learners. The game process engenders teamwork, communication and collaborative spirits among the students. None of the teams identified a team leader, but instead all members acquired a role, such as that of the computer operator, the manager and the journal keeper. There were only a few occasions when they were asking for the researcher’s guidance, as they preferred to solve any problem or difficulty on their own.
It should also be mentioned that the cooperation was considered by the majority of the students as one of the most positive aspects of the application. Some of them wrote characteristically on the feedback/satisfaction questionnaire:

Student 1: "I collaborated perfectly with my schoolmates!"
Student 7: "I enjoyed teamwork"
Student 12: "Collaborating with my friends was great!"
Student 17: "It was very nice that we had to work together in the game"

4.4 Student Satisfaction

Furthermore, after the interventions, students’ views on the application they had used were elicited through a feedback/satisfaction questionnaire (Figure 12).

![Students' Satisfaction](image)

**Figure 12:** The number of students in relation to their satisfaction of the application

All students reported satisfaction and enjoyment from their engagement with the game and commented that they were able to learn through playing. Over 60% of the students commented that the game improved their knowledge in English and Geography and almost 80% found the game challenging, interesting and exciting. In addition, 10 out of 17 students reported collaboration and teamwork as one of the most positive aspects of the game process. Moreover, according to researcher’s journal, throughout the whole gameplay, students were drawn to the game, especially to its attractive illustrations.

5. Conclusion

This paper has suggested a game-based concept for teaching a foreign language based on a case study implemented in a Greek primary school. The results suggest that the use of foreign language learning strategies as well as the geography-related content were facilitated and improved. In addition, reading skills, lexicon, motivation and collaboration were enhanced.

The reason that this game was selected for the described approach is the fact that it includes authentic material with a meaningful purpose, no confusing graphical interface or complicated control schemes. Instead it utilizes technological tools (such as Google Earth, QR Codes and websites) that can be easily manipulated by educators without any specific technological knowledge. Moreover, it can be applied in all levels of education in order to teach a variety of subjects and enhance a range of learning skills. Therefore it comprises an ideal educational tool to be implemented in a range of different learning contexts and used for a variety of teaching
purposes. Thus this paper can also operate as guide for educators, willing to apply such approaches and techniques in their classes but are not very technically competent. The core idea is a game approach, based on an idea which is close to the students’ interests, enriched with authentic and meaningful content, within the context of the subject to be taught.

Another important issue implied by the present study is that the less advanced students benefited from the game. Although Egenfeldt-Nielsen (2005: 221) states that “the best students were capable of connecting the two modes – playing and learning – whereas the least successful don’t make this connection”, it should be highlighted that there should be more explanation given in relation to this conclusion. The present study showed that there were students who were not very advanced, but who thanks to the game, were able to implicate themselves a great deal in the learning activities.

Furthermore, an important issue that is implied through this paper and should be taken into serious consideration is the urgent need to change teaching methods in order to enhance the skills that future citizens will need in a digital society. According to Prensky (2005) teachers should learn to use computer games as tools that provide engaging and effective learning experiences for students. However, teachers with little experience in the use of computer games are reluctant to use them (Gros, 2007). For this reason, it is important to design guides that can explain the merits of games to teaching staff and enable them to use them in a way that is oriented far more towards the acquisition of the knowledge required by the school curriculum (Gros, 2007). However, it should be taken into serious consideration that there is a series of basic issues that should be investigated not only from the point of view of educators but also by the computer game designers. For example, an important issue of computer games to be investigated is the time that is necessarily required to produce an activity. Generally, the games require many hours and, on occasion, it is difficult to establish the sequences of play that should be significant for both the students and school curriculum. In this sense, the most efficient thing to do is to let students continue to advance their knowledge of play outside the classroom, via the provision of access to the game in the school.

Finally, the aforementioned game concept developed can be seen as a template where different instructors can introduce different knowledge and contexts to apply game-based learning for their particular subjects and specific learning goals. Moreover, in implementing, but also researching CLIL, the focus usually lies on ‘typical’ school subjects fostering cognitive learning. Future work can also be carried out to foster others forms of learning. Apart from that, most research on CLIL is concerned with primary and secondary education. As recently GBL has also been proposed for adult education, a new form of interactive content is worthy of exploration for learning purposes. Last but not least, future work includes the transformation of the aforementioned game into a more interactive one, perfectly suited for additional speaking and listening activities and grammar-focused activities through the implementation of post-playing tasks designed around the content of the game.

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Games as a Platform for Student Participation in Authentic Scientific Research

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Abstract: This paper presents results from the design and testing of an educational version of Quantum Moves, a Scientific Discovery Game that allows players to help solve authentic scientific challenges in the effort to develop a quantum computer. The primary aim of developing a game-based platform for student-research collaboration is to investigate if and how this type of game concept can strengthen authentic experimental practice and the creation of new knowledge in science education. Researchers and game developers tested the game in three separate high school classes (Class 1, 2, and 3). The tests were documented using video observations of students playing the game, qualitative interviews, and qualitative and quantitative questionnaires. The focus of the tests has been to study players’ motivation and their experience of learning through participation in authentic scientific inquiry. In questionnaires conducted in the two first test classes students found that the aspects of doing “real scientific research” and solving physics problems were the more interesting aspects of playing the game. However, designing a game that facilitates professional research collaboration while simultaneously introducing quantum physics to high school students proved to be a challenge. A collaborative learning design was implemented in Class 3, where students were given expert roles such as experimental and theoretical physicists. This significantly improved the students’ feeling of learning physics compared to Class 1 and 2. Overall the results presented in this paper indicate that the possibility of participating in authentic scientific experiments, which this class of games opens, is highly motivating for students. The findings also show that the learning design in the class setting must be considered in order to improve the students’ experience of learning and that various design challenges remain to be addressed even further.

Keywords: Scientific discovery games, science education, learning games, game-based learning

1. Introduction

The use of games and simulations in science education was introduced in the 1970s. In the early 1980s the potential of games and simulations as new teaching tools was extensively discussed (Ellington et al., 1981). In the early 1990s the first IT-based educational games for exploration of the natural sciences and technical subjects were developed (Egenfeldt-Nielsen, 2005). Since the beginning of the new millennium, there has been an increasing awareness of the opportunities that new types of commercial computer games can offer science teaching, and of developing new formats framing aspects of real-life science learning environments that allow players to tackle complex problems in simulated professional contexts (e.g. Squire & Klopfer, 2007; Magnussen, 2007). These games supported new practices in science education, such as student development of new professional inquiry tools for imaginative creation and representation of new knowledge. These new practices are influenced by non-school factors such as fictional characters and authentic professional tools (Magnussen, 2008). More recently, scientific discovery games have been developed in which player contributions to real-life research challenges are an integral part of the game. In this class of games complex scientific problems are translated into puzzles and a game-like mechanism is provided for non-expert players to help solve the presented problems (Cooper et al., 2010).
The current paper presents the design considerations and test results of the adaptation of a new scientific discovery game for in-school learning environments. Some of the main design considerations include making the complicated scientific background understandable, getting the students engaged in the process of generating new knowledge, and creating a sufficiently strong connection from the research challenge to the core student curriculum.

2. Background: Gamified research collaboration in science education

One of the main focuses in the development of science game formats over the past 10 years has been how the medium of games can introduce new approaches to authentic science education (Gee, 2003; Magnussen, 2008). Concrete examples are the so-called Profession Simulation Games or Epistemic Games. Prime examples of these are profession simulation games that simulate objectives and environments of a specific profession by using the technology, tools and/or methods of the profession.

2.1 Profession Simulation Games

The objective of Profession Simulation Games or Epistemic Games is to draw on the game medium as a framework for the complex interdisciplinary creation of new knowledge and innovative solutions. Examples of this type of games are students playing engineers identifying polluted sites (Squire & Klopfer, 2007), urban planners planning a central urban area (Shaffer, 2006), or forensic experts investigating murder cases (Magnussen, 2007). Profession Simulation Games are designed to meet the official educational objectives (Magnussen, 2008), while the aim of Epistemic Games are:

“...to create the epistemic frame of a socially valued community by re-creating the process by which individuals develop the skills, knowledge, identities, values and epistemology of that community” (Shaffer, 2007, p. 164).

The motivation for developing this type of games stems from a critique of the teaching of standardised skills to children in today’s school system (Gee, 2003). It is argued that few schools teach students how to create knowledge; instead, students are taught that knowledge is static and complete. This means that they become experts at consuming rather than producing knowledge (Sawyer, 2006). As a result, the medium of games has been used to create environments with simulations of complex real-life situations, where students have to think like professionals and solve problems in innovative ways within the context of the knowledge domain of the profession defined by James Paul Gee as:

“Any actual domain of knowledge, academic or not, is first and foremost a set of activities (special ways of acting and interacting so as to produce and use knowledge) and experiences (special ways of seeing, valuing, and being in the world). Physicists do physics. They talk physics. And when they are being physicists, they see and value the world in a different way than do non-physicists.” (Gee, 2005, p.1)

Interesting issues arise, however, in relation to this class of games that need to be addressed when discussing the integration of creation of new knowledge and authentic science practice in science education. Even though the games integrate professional values and tools, they remain simulations of professional practices. This aspect of the games brings up the matter of whether students learn to work as a scientific expert or whether they learn how to be a scientific expert. This may depend on various design elements of Profession Simulation Games. First, the clients and experts that students collaborate with in the games are fictional characters with fictional problems that do not necessarily have relevance outside school. Secondly, the fictional problems to be solved in these games often follow a linear path and have a clear starting and ending point. This is clearly different than real-life professional problem solving, where the processes are more multidimensional. Finally, even though these types of games have been shown to support student creation of new process tools, the solutions are often pre-defined and already known by the teachers (Magnussen, 2008). This stands in contrast
to the real-life open-ended tasks professionals face which can be carried out in various ways. Here, the chance of success or failure is always an issue of consideration. This raises the question: whether students, in spite of the games involving authentic values and tools from a given professional practice only learn about scientific expertise in a scenario adapted to the school context or whether they experience being part of a knowledge domain as participants in a scientific process that includes an authentic professional context.

2.2 Scientific Discovery Games

The development of the so-called Scientific Discovery Games within the past couple of years brings new elements into the issue of game-based participation in a knowledge domain. The main goal of this class of games is to create a platform that enables and motivates players to contribute in solving scientific problems (Cooper et al., 2011). The most well recognised example of this class of games is Foldit which is an online puzzle game where players participate in folding amino acid chains to form new protein structures. Presented with a primary protein sequence or partially folded structure, players need to find the – often unknown - lowest-energy three-dimensional structure. Players manipulate the protein structure by pulling, twisting and tugging the protein backbone and side chains into various configurations (Good & Su, 2011).

Scientific discovery games contain specific design features that distinguish them from the majority of other games (Cooper et al., 2010; Good & Su, 2011). First, Scientific Discovery Games are designed for non-expert players to advance a scientific domain. As a result, the visual features and graphics must enable beginners to experiment with highly complex solutions and scientific information. This requires that the game interface is designed to gradually introduce beginners to a highly complex field while simultaneously motivating them to play the game. Another distinctive feature of this class of games is that the problems do not have pre-defined solutions; even the game designers do not know the answers, of which there are potentially more than one. This also implies that the interactive design must make exploration and experimentation processes possible while simultaneously respecting real scientific constraints. Consequently, the scoring mechanism must reward several distinct player strategies while remaining true to the latest knowledge about the scientific phenomenon (Cooper et al., 2010; Good & Su, 2011).

The goal of the research effort presented in this article is to expand the Scientific Discovery Game concept to be included in an educational context. An educational design has been created where students gain first-hand experience with creating new scientific knowledge in collaboration with researchers. The design aims to create the experience that this knowledge is not static, but constantly evolving. However, there are educational challenges in designing this type of games. Scientific Discovery Games have the potential to introduce authentic experiments and creation of new scientific knowledge into science education. Therefore, it is crucial to understand if and how the game environment contributes to students’ experience of participating in research. Moreover, we also need to understand the main motivating factor for playing this type of games in school; is it competing against other students, contributing to science, or collaborating with scientists? Understanding the perceived learning of students and implications of introducing this type of games to different types of students is thus another focus point in the research presented in this paper. A final challenge for the educational designers is the observation that student perception of learning is strongly affected by the success of relating the context of the game to the core curriculum. In this paper we present the design and initial test results of the adaption of a Scientific Discovery Game, Quantum Moves, to a school environment in order to teach quantum physics to high school students in Denmark. We furthermore discuss the potential and challenges of designing this type of games for science education.

3. The Game Quantum Moves: Gamified Quantum Computer Research

The game, Quantum Moves, represents a collaborative effort between researchers in physics, computer science and game-based learning at the interdisciplinary AU Ideas Pilot Center for Community-Driven Research, established January 2012. The focus of the quantum game project is the research-based production
of a game-based platform for player participation in quantum research, more specifically in the research of building a quantum computer. In the following the concept of quantum computers and the mission of Quantum Moves are presented briefly. Although it is not the intention of this paper to give a detailed account of the online game, some physical details are included here to give an insight into the new concepts that students were exposed to during the interventions into the high school classes. The detailed considerations concerning the optimal didactic framing of the intervention are discussed in chapter 4.

3.1 Quantum computers and the AU candidate

All data in regular computers are stored in vast amounts of small electrical devices called transistors, each representing either the value 0 or the value 1. In a quantum computer (QC) these so-called bits are replaced by individual quantum systems such as atoms, electrons, ions, or photons. Due to the fundamental principle of superposition these quantum bits can be both 0 and 1 simultaneously. This means that many calculations can be performed in parallel and even a relatively small quantum computer would contain more computational power than all conventional computers combined. Very small QCs have existed for over a decade but to date the world record is a mere 14 quantum bits.

The building blocks in the Aarhus University (AU) candidate for a large quantum computer are extremely cold atoms arranged in a periodic pattern similar to eggs in an egg-tray. The physicists have recently participated in the experimental creation of such a crystal containing hundreds of atoms (Sherson et al., 2010) and the remaining challenge is to figure out how to perform operations on this system. Recent theoretical work has indicated this to be possible by using a tightly focussed laser beam (a tweezer of light) to pick up individual atoms and transport them around in the crystal (Weitenberg et al., 2011). This movement, however, poses a large challenge because any sudden movement will cause the atoms to slosh in the tweezer. This sloshing will translate into errors in the calculations and the basic unsolved challenge is therefore to find the best way of moving the tweezer containing the atom to minimize the final sloshing.

3.2 The Scientific Discovery Game Quantum Moves

The researchers have tried out multitudes of different motional paths in extensive computer simulations but believe that they have not yet found the best solutions for moving the atoms in the AU candidate for a QC yet. To solve this problem, they developed the Scientific Discovery Game, Quantum Moves, in which players try out their solutions in a graphical simulation interface. A particular path consists of a choice for the position and intensity of the tweezers. For each attempt a player makes, a score is calculated based on the quality of the resulting quantum computer. The performance of every player is logged centrally and the overall highest score will always correspond to the state of the art of the research field and can thus be improved as people play. We hope that the approach will be effective not only due to the sheer quantity of potential players but also because players can potentially apply the distinctly human skills of pattern recognition and intuition to perform a much more intelligent optimisation than computers can.

Figure 1: Examples of tutorial games to introduce the quantum mechanical concepts and methods needed to understand the scientific challenge. (A) An illustration of the allowed quantum mechanical states and sliders to
create mixtures of these. (B) A small tutorial game teaching the student how to remove kinetic energy from an oscillating atom.

The educational version of Quantum Moves (EQM) has two parts; a tutorial part and a scientific part. The tutorials consists of games and simulations that introduce players to quantum physics (figure 1) and where the game mechanics of moving the atom is introduced (figure 2 A). Examples of actual scientific research games in different iterations are shown in figure 2 B and figure 3. Figure 1 (A) illustrates the allowed quantum mechanical states and offers sliders to create mixtures of these. The basic lesson is that if the atom (represented as a liquid-like substance inside the graph) is purely in one of the allowed states of the well, it will not move in time but in a mixture it will. In figure 1 (B) an atom is displaced in the well and therefore starts oscillating. The user then has to remove the kinetic energy by moving the well from side to side. The data on the position of the atom versus time is listed to the right, allowing students to transfer the information to a plotting program to analyse the results of their experiment.

3.3 The iterative adaption of Quantum Moves to high school interventions

The first types of tutorials – as the ones show in figure 1 – are the most important in this context because they were developed and iteratively modified with the specific purpose of establishing as close a link between the physics of the research question and the core curriculum in high school interventions. At the end of each intervention the students were then exposed to the version of the online game at the time of that particular intervention. This explains why the students were exposed to two different versions of the online game (figure 2 B and figure 3). One example of the iterative design is the addition of the possibility of extracting the data of the position of the atom versus time as shown on the right hand side of Figure 2 B. In initial interventions the position of the atom at various times was simply visualised in a graph to the right of the game window. Later we added access to the actual data because we found that the process of extracting the data, importing it into a well-known program, and plotting it there created a much more active learning atmosphere in the class room.

Figure 2: Screen shots from the online Quantum Moves game (A) An introductory challenge where players must transport the atom to the striped target area without hitting the walls. (B) The real scientific challenge where players must deliver the atom in the target area without any sloshing.

4. Investigating the game in high schools

The EQM platform has been tested in Danish high schools with students aged 17 – 20. The focus of these tests has been to investigate the following research perspectives. First of all, the aim of the study is to understand which new practices this class of games introduces into science education. Here, we focus particularly on investigating if and how it strengthens students’ perception of participation in authentic scientific research. Secondly, we aim to understand students’ motivation for playing scientific research games and whether the motivation is intrinsic (related to game factors) or if students are extrinsically motivated by factors for instance related to the research participation. Thirdly, the studies have focused on investigating the students’ perceived learning: What influences their experience of learning physics from the game and how does the game initiate
new learning approaches for different student groups. These research perspectives have been tested in cycles of research and development which will be described below.

4.1 Methodology and test design

The methodology used in the development of the didactic components of EQM followed a design-based research process and involved various design cycles, interventions, analyses and redesign (Brown, 1992). In design-based research the focus is both on developing learning environments as well as domain specific theories (Cobb et al., 2003). The method serves as a methodological framework for integrating differing methods at the various stages of research and development (Squire, 2005). In the first phase of design of and intervention with the game, focus was on understanding whether it was intrinsic game factors, e.g. elements of competition, that motivated the students to play the game or extrinsic factors, e.g. research participation, that was the driving force. A beta version of the game (see figure 3) was completed in early 2012 and interventions were conducted in two high school classes. Class 1 consisted of 20 students 17-19 years of age in their second year of high school, while Class 2 comprised 20 students 17-20 years of age in their third and final year of high school. In both classes the teacher introduced basic quantum physics principles (as those discussed in Section 3 and Figure 1) in the lectures preceding the intervention. Quantum researchers from the development team introduced EQM to the classes along with their view of the link between the curriculum and the research challenge. Based on the subsequent discussions it was a clear observation that the researchers could present the particular parts of the curriculum much more engagingly and convincingly than the teacher. We speculate that the reason could be the perception that the researcher represents a living field of knowledge with a close connection to the curriculum and the research frontier, whereas the teacher represents a static and artificial collection of facts. Following the introduction, the test of the different sub-games was conducted over two class periods. Students’ game participation was documented using video observations combined with short semi-structured qualitative interviews (Kvale, 1996) of students and teachers during play sessions. The aim was to identify new types of practices in the interaction with the game. In addition, qualitative interviews were conducted with the entire class and their teacher after each play session. The classes were also asked to fill out a written questionnaire after the test, answering qualitative questions such as “What was the best/worst part of playing the quantum game?” and “How does playing the quantum game differ from your other physics teaching?”. Quantitative questions included “Rate the following - Have you learned physics by playing the game?” where students were asked to rate the statement on a scale from 1 (not at all) – 5 (a lot).

![Figure 3: An early alpha version of Quantum Moves tested in Class 1 and 2. Players have to move the atom from a well on the right to a well on the left while agitating the atom as little as possible.](image)

Focus of these two first tests was to collect data on motivational aspects of playing the game and the students’ experiences of learning quantum physics from the game. In the second design-based research cycle of problem definition, design, intervention and analysis focus was on strengthening the students’ experiences of learning quantum physics. Based on results from the initial tests, the game was further developed and a new version was tested in April 2013 in a high school in west Denmark (Class 3).
With the aim to strengthen the student’s experience of participating in and learning authentic professional quantum physics practice a didactic design was developed in collaboration with the class teacher. The focus of the design was to combine theoretical approaches, experimental practice using physical tools, and play with game simulations. The goal was to boost the authentic aspects as well as the theoretical and experimental practices by assigning students roles in the game as experts. This design was inspired by elements of simulation games on specific professions (Magnussen, 2007) and notions of collaborative learning (Dillenbourg, 1999). The game test session in Class 3 was conducted over four school periods and had been introduced in previous lessons by the teacher. At the beginning of the first lecture the students were introduced to a simulated professional setup where they played the roles of a research team of physicists working on the development of a quantum computer by optimising the laser movement to transport atoms. Students were divided into three different teams, each one representing an area of expertise. One group comprised experimental physicists who were working to better understand the transport movement by doing experiments on a classical analogue to the quantum problem. The second group of experts were IT professionals specialised in simulations, who performed virtual experiments in the games. The last team worked theoretically and focused on understanding the mathematics behind the various elements of the atomic transport. The teacher assigned each student to the particular group best matching their interest and skill level. Students worked in their group for three class periods. They were then mixed with students from the two other groups to share observations and to produce a poster or film with their conclusions. The sessions were documented through video observations, questionnaires and qualitative interviews similar to the studies in Class 1 and 2.

4.2 Results Tests Class 1 and 2: Motivation and Authenticity

Similar observations were made in the two high school classes, Class 1 and 2, where the game was first tested. Students in the two classes were initially intensely interested and motivated and worked continuously with the game during the two class periods. At the end of the second class period, some students had begun to lose interest. This was especially the case for the youngest group of students from Class 1. The test was set up so that the students had to download the game on their own laptops prior to the test session. The majority of the students used their own laptops, but a few shared laptops in groups of two or three. In both classes, students discussed strategies and patterns for how to transport atoms in different environments while playing. They also discussed their scores and commented on results, high scores eliciting cheering. Scores seemed to be a central motivating factor for the students. However, results from the qualitative interviews after the test and written questionnaire showed that other elements contributed as motivating factors as well. The answers from the interviews and the questionnaire varied according to what participants thought was the best part about playing the game.

![Figure 4](image-url)

**Figure 4:** The answers in Class 1 on the question “What is the most interesting aspect(s) of playing the game”. Seven students answered the questionnaire. The students were allowed to choose more than one of the four options.
The questionnaire was unfortunately completed by only 7 out of 20 students in Class 1. The results therefore carry no statistical significance in themselves but are included to exemplify student opinions. On the question “What is the most interesting aspect(s) of playing the game?” 5 of the 7 of students in Class 1 answered “To participate in real scientific research”, the other options where each chosen by 2 of the students, see figure 4. These results show that research participation was the primary motivational factor in this class.

In the qualitative interview with the entire class, the students were asked what the biggest difference between playing the game and normal teaching was. One student stated that, “In the normal teaching you only calculate the results, while in the game you get the feeling of directly doing the experiment”. When students and (after the interviews with the students) teachers were asked to expand on this comment, they explained that what happened in the game felt like an experiment compared to class lab work, which they saw as mere demonstrations. This indicates that students exposed to EQM experience participating in actual quantum physics experiments in sharp contrast to the highly theoretical level at which this subject is conventionally taught in Danish high schools.

Class 2’s answers to questions about motivational factors differed slightly from the answers in Class 1 but overall showed similar results, see figure 5.

![Figure 5](image-url)  
**Figure 5**: The answers in Class 2 on the question “What is the most interesting aspect(s) of playing the game”. 13 students answered the questionnaire. The students were allowed to choose more than one of the four options.

These results are interesting because educational games are often viewed as a tool to motivate students to participate in educational activities. Here games become a tool to frame or facilitate processes where the motivation lies in the subject that the game covers or in the research context outside the school context. One student described that the most interesting aspect of playing the game was knowing, “that you have a real chance to help enable a quantum computer. It also irritated me when I didn’t get as many points in the game as my friends did, which got me to play the games even more.” In response to the same question, two other students explained, “The best thing about the game is that it is one of the few games in this world that you can actually use for something real” and “that the games were relevant to physics, and that you have the chance to make a difference, even if it’s not a vital one, in the development of quantum computers (Cool!)”. The first answer indicates that the focus that some students have on scores does not necessarily exclude a focus on research collaboration. The two subsequent answers show that it is primarily, if not exclusively, the fact that they are contributing to research that motivates them to play the game.

During the interview conducted immediately after the test in Class 2, 2 - 3 students stated that they did not feel as if they had learned physics. They explained that this was due to the fact that moving the atoms was a simple task that did not expand their understanding of quantum physics. The questionnaire also showed that a larger part of the students did not experience being taught physics through the game to a significant degree.
When asked whether they had learned about physics from playing the game using a five-point scale ranging from 1 for “not at all” to 5 for “a lot”, most of the students answered 2, and none answered 5, see figure 6.

![Did you learning physics from playing the game?](image)

**Figure 6:** The answer in Class 2 on the question “Did you learn physics from playing the game?” on a range from 1 (not at all) to 5 (a lot). 13 students answered the questionnaire.

Although the results seem discouraging, they were no surprise to the development team, since in this early intervention little had been done to align the game simulations with the particular curriculum of the students and the intervention was too short to accommodate extensive learning. Furthermore, in the interview with the teacher after the test session, the teacher challenged the understanding that students had of “learning physics”. He argued that their understanding of “learning physics” was to advance their skills in solving concrete problems related to their final exam. He added that in his opinion the contact with the researchers and the game had given his students a deeper understanding of quantum mechanics that he could not have given them as a teacher alone. Although not explicitly tested at the final exam, such “nature of science” is also a part of the curriculum according to the teacher, but understandably the students had a tendency to value learning that prepared them for the final upcoming exam more highly. The conclusion was to aim future intervention design at extending the “nature of science”-like understanding of the concepts of quantum physics, while also incorporating more explicit learning.

In summary, the results from these two classes showed that the main motivating factor was research collaboration or solving physics problems. 54% of students in Class 2 experienced learning no or little physics from playing the game. The game and setup in the class thus provided a strong experience of participating in an authentic experiment, but less evident experience of learning physics from the participation. Teachers in both classes also commented on the “tangible” approach the games had to a highly theoretical subject which is very different from “normal” teaching on this subject. In Denmark, high school physics is taught at a highly theoretical level, which may be the basis for the student’s comment that they “only calculate the results” in “normal” teaching, but that the game gave them the feeling of “directly doing the experiment”.

### 4.3 Test in Class 3: Experimenting with strengthening the student experience of learning

Class 3 comprised a third-year high school class consisting of 20 students 17-20 years of age from a technical high school in west Denmark.

The feedback and findings in the tests conducted in Class 1 and 2 suggested a different focus for the redesign of EQM. Part of the new focus for the further development of the game was to strengthen the students’ experience of participating in an authentic science experiment as this had proven to be a strong motivating factor for some students. Moreover, our hypothesis was that the authentic research collaboration aspect of the game could contribute with new didactical input to science education. One of the ways we strengthened the authentic aspects of the game was to make the researchers more visible on the game’s website.
Another issue that the project team responded to with respect to the second test was making improvements related to the teacher’s comment about a tangible approach to a highly theoretically subject. The teacher at Class 3 was interviewed on this and other topics before the test. In this interview she explained that she had observed that this “more intuitive” approach to a highly theoretical subject appealed to a group of students that was exceedingly interested in the subject, but felt that it was difficult. These teacher’s statements were in accord with students’ comments from Class 1. As a result, the test focused on investigating this issue further.

The final area of focus for implementing and testing the game in Class 3 was to strengthen the students’ perceived learning on the subject at both an experimental and theoretical level. To strengthen the EQM learning environment a collaborative learning design inspired by profession simulation games (Magnussen, 2008) was, as described earlier, implemented in Class 3. Students were divided into three different teams by the teacher dependent on their individual skills. Each team represented an area of expertise: experimental physicists working on understanding movements of atoms better by doing analogous experiments, IT professionals specialised in simulations doing virtual experiments in the game, and theoretical experts focusing on understanding the mathematics behind the various elements of the movement of the atoms. Students worked in groups with similar expertise for three class periods and were then mixed with students with different expertises to share results and to produce a poster or film with their conclusions. Overall the students worked intensively with the game in the different teams. The simulation of the different professional approaches in the authentic framework of contributing to the scientific domain of these professions appeared to spur complex discussions concerning the results obtained from using physical experimental tools compared to the virtual experiments in the game. In the questionnaire students were after the game asked whether they had learned about physics, see the results in figure 6. In Class 3 29 % of the students answer 5 (“a lot”), which is a huge improvement to the result in Class 2 where no one answered 5.

**Figure 6:** The answer in Class 3 on the question “Did you learn physics from playing the game?” on a range from 1 (not at all) to 5 (a lot). 14 students answered the questionnaire

In summary results in Class 3 showed that 79% of students answered 3 or above compared to only 46 % in Class 2. The above results indicate that the new design has strengthened the students’ experience of learning physics. This seems to generally for the class, but could potentially be specifically for the less theoretically skilled students. For this group of students EQM offers experimental approaches to quantum mechanics through playing by making direct manipulation atoms possible in the game.
5. Discussion and Conclusions

The results presented in this paper show that the educational adaptation of Scientific Discovery Games, enabling participation in authentic scientific experiments, are highly motivating for students. However, the findings also show that the learning design in the class setting must be considered seriously in order to improve the students’ experience of learning and that various design challenges remain to be addressed even further. In order to successfully develop and introduce Scientific Discovery Games into science education we need to focus on how the game operates and the didactical aspects that can strengthen important elements in these games, such as authenticity and authentic experimentation. This paper described how a Scientific Discovery Game can be didactically designed to fit a classroom setting by merging aspects from simulation science games about specific professions with the research collaboration approach.

Furthermore, the complexity of playing the game needs to correspond to the complexity of the scientific challenge. This, however, is not straightforward, if even possible, due to the research nature of the game as the “rules” of the research area determines the game mechanics. Another aspect that needs further investigation is how this type of game can motivate weaker students in science education. In interviews with teachers from Class 1 and 3 the teachers stated that the intuitive or tangible approach of the game to quantum physics encouraged weaker students to participate more actively.

The students’ responses described in this paper indicate that Scientific Discovery Games offer new approaches to integrate authentic knowledge creation and scientific practice into school science education for specific groups of students. Finally, further research is needed concerning how role playing and collaborative learning approaches can further strengthen students’ learning experiences and the outcome of that learning.

References

The Playful and Reflective Game Designer

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Abstract: A group of first-semester engineering students participated in a game design course. The aim of the course was to learn how to design computer games and programming skills by creating their own games, thereby applying their game-playing experiences to gain knowledge about game design. The aim was for students to develop a more critically reflective perspective on video games and game design. In applying their game experiences, they developed their own digital prototypes and participated in reflective discussions on the concept of games: what makes them interesting and how they are constructed. The students used the GameMaker programming tool, which can be used without any prior programming knowledge. The tool allows for the easy development of 2D game prototypes. The didactic approach was based on play as a lever for the design process, and on constructionist and reflective learning philosophies. Playing games constituted an integral element of the design process; new code added to the program was tested by playing the game. The students were constantly alternating between playing and adding and revising code. The learning environment where games were played and developed could be considered to be a sandbox where experimentation was a motivational factor for the students, as they could make mistakes and try out creative ideas. Although the constructionist learning approach promoted creative and innovative learning, it did not develop competencies in articulation and analysis. The aim was for students to reflect on games in order to promote explicit knowledge. Based on the theory, we consider retrospective reflective discussions in the classroom and their programming experiences reinforced the learning process. In summary, we present the students’ first progression from native consumers in the game world to becoming reflective designers. Along their journey, they developed a reflective practice and an understanding of the profession they were entering. The article also throws light on the very dynamic and fruitful relationship that exists between playing games and designing games.

Keywords: Learning, play, constructionism, reflection, game-based learning, game design, serious games, university pedagogy

1. Introduction

A group of first-semester students participated in a course to design and programme games. The aim was to learn about game design and programming by creating, testing and playing their own games. The didactic approach was based on play as a lever in the design process, and on constructionist and reflective learning philosophies.

They used the programming tool GameMaker, which can be used without any prior knowledge of programming (Habgood, 2006 and 2007). GameMaker is ideal for developing game prototypes in 2D. An integral part of the process of game development, involved the students playing the games. The idea was to provide both “low floor” (easy to get started) and “high ceiling” programming tools (to create increasingly complex projects over time) (Resnick, 2009). The intention was for the students to experiment, learn from making mistakes and create interesting games.

Papert (1993) used programming as a tool to teach children mathematics. By interacting with the programming tool, the children constructed programmes and developed their knowledge of mathematics. He thought of the programming tool as “an object to think with”. Our aim was to set up a similar learning process in this course.

Additionally, we wanted the students to convert some of their game-playing experiences to actively create knowledge about game design. It was intended to give students a more critical and reflective approach to computer games and game design.
The students in the study had all played a range of computer and console games since they were 5-6 years old and were, therefore, regarded as “native consumers” in the game world. These young people grew up playing video games as an integrated element of their everyday lives; some had played intensively, while others had played more sporadically.

In order to make the conversion from experience to knowledge, they had to distance themselves from the consumer role. They needed to develop the capacity to reflect on what constitutes a game, what it is that makes a game interesting and on how games are constructed. These reflections informed their development of interactive prototypes.

The students were enrolled on the three-plus-two engineering programme “Learning and Experience Technology” at the University of Southern Denmark. In addition to this course, they also followed lectures on game design and game theory, which included Fullerton (2007), Zimmerman & Salen (2004), Csikszentmihalyi (2005), Juul (2005) and Sicart (2008) in the reading list.

The research question in this article is: How can construction, play and reflection enrich the game design process for engineering students?

The research method is inspired by design-based research. The intention was to produce new theories and practices based on digitally-supported learning and teaching in naturalistic settings (Majgaard, 2011a; van den Akker, 2006; Barab, 2004). The method is interventionist, i.e. it involves an element of design, it takes place in naturalistic contexts, and it is iterative. In this study, we designed a new practice for creating games in the classroom. The study was based on interventions in the classroom, teaching materials and student products. Finally, we undertook a qualitative email interview with six students (Kvale, 1997). These interviews reflected the students’ views on gaming and what they learned by playing and designing games. They were questioned about specific gaming experiences and how these affected the design.

Organisation of the paper: First we offer a brief summary of the course and reflections on the didactics. We then present the underlying theory, which focuses on the dynamics between play, reflection and active participation. The students’ active participation promotes reflection and acquisition of new knowledge. This underlying theory is based, in particular, on Schön’s ideas on the practitioner’s active participation and reflection on practice (Schön, 2001; Argyris, 1978). In addition, the focus is on the relationship between tacit and explicit knowledge (Scharmer, 2000 and 2007). The dynamics between tacit and explicit knowledge are brought into play in innovative design processes. This is followed by a discussion of the learning potential that emerged in the study. The paper ends with a summary and conclusion. This article is an extended version of the ECGBL (European Conference on Games Based Learning) conference paper: “Creating Games in the Classroom – from native gamers to reflective designers” (Majgaard, 2013). In this version, we unfold the importance of play as a part of the design process. Additionally, we explain the terms reflection-in-games and reflection-on-games more clearly.

2. Background: Description of the course “Game Programming”

The course, intended for first-semester students with no prior programming skills, ran over 15 weeks, with two weekly one-hour lectures. The course combined theory and practice. The primary aim of the course was to teach the students basic game programming. A further aim was for students to gain knowledge of what makes games interesting and of game design methodology. They would also gain practical experience in iterative development processes.

The programming platform was the programming tool GameMaker. At the start of the course, the students imitated and copied already programmed games, in order to become familiar with game programming concepts, such as sprites, objects, structures, events, actions, rooms, sound and motion (Habgood, 2006 and 2007). The students played GameMaker games and subsequently developed their own versions of the games.
At first, their own versions were copies of existing example games, but gradually they developed creative variants.

In the fifth week, the students embarked on their first bigger project task – to develop their own game idea. The requirements for the game were: at least one level; at least two objects moving; sound; collisions handling; title page and dialogue box or a high-score list. They had three weeks to develop the first version; each week, there was a brief follow-up in the classroom.

At the end of the three weeks, the students presented their games in class. This led to a discussion of the strengths and weaknesses of the games and to the next project task: the students were to formulate a prioritised list of requirements for the next version of their game prototypes. The aim was to encourage the students work iteratively, set goals and assess what realistically could be achieved within a deadline. Most of the students carried out three iterations.

3. Game design and learning theory: Play, constructionism and reflection

Ideas around bringing games into the classroom are often based on the motivational nature of games; we further hoped to make the students’ academic learning easier and more fun (Kafai, 2006). According to Kafai, there have been relatively few attempts to make games for learning – as opposed to playing games for learning. Kafai suggests that, rather than embedding “lessons” directly in games, students could be provided with greater opportunities to construct their own games. She suggests that constructionistic game design has equal if not more potential to engage learners’ enthusiasm. An aspect of the learners’ enthusiasm could derive from play.

3.1 Play and proximal development

The student might adopt a playful attitude when developing and playing their games. Play is an activity where the learner can use imagination and experiment. Play can become a framework that promotes experimental and exploratory participation (Bateson, 2000). Play potentially provides a special way of participating in an educational context that can promote co-creative and imaginative activities. When we made up our didactical plans, we wanted play to be a driver in the development process. We considered that play could be a motivational factor and provide a framework for experimentation. Vygotsky links play and learning. He is particularly known for the concept of “the zone of proximal development” (Vygotsky, 1978). The zone of proximal development is the distance between what the child can learn by itself and what can be learned in collaboration with peers or a teacher (Vygotsky, 1978:86). We applied Vygotsky’s ideas in our study. The level of academic learning goals should match the learner’s current academic level or be slightly above it. If academic goals are set beyond the zone, it might very well be too frustrating or impossible for the student to reach the goals. But then again students might have different levels of frustration.

Play creates space for the zone of proximal development. Vygotsky believes that the child’s play often occurs in the zone of proximal development. Play can be used as a tool for learning and play can very well be a lever for learning. Play allows learners to do something they would not otherwise have been able to do on their own initiative.

*Play creates a zone of proximal development of the child. In play a child always behaves beyond his average age, above his daily behaviour; in play it is as though he were a head taller than himself.* (Vygotsky, 1978:102)

In our didactical design, we planned for the students to play games as part of the design process. And we aimed for the students’ zone of proximal development. Play provides the opportunity to simulate and explore imaginary situations in practice and in association with others. By playing, the learner develops a deeper
understanding of a given field. The game helps to develop abstract thoughts about the given field and gives the learner new forms of desires and interests (Vygotsky, 1978:100).

Vygotsky suggests that the learner can reach the zone of proximal development by playing, collaborating with peers or a teacher. It was our intention to create a space for all of these possibilities in the classroom. In the didactical design, we wanted to promote play by encouraging the students to play games as a part of the development process. We provided a metaphorical ‘sandbox’ for learning and experimentation.

While testing and playing games, the students were to develop game programmes. Programme development is, in our view, a constructionist and reflective process. This perspective is unfolded below.

3.2 Constructionism and reflection

The learning philosophy was based on constructionism, where the learner constructs knowledge while creating constructions in the real world (Papert, 1993). Constructionism was inspired by Piaget’s concept of constructivism. Although Papert’s focus was on learning mathematics, we employed his learning tools to support both physical and virtual constructions in game design. Resnick (2009) developed the idea of designing games and simulations and suggested programming as a fundamental skill to which everybody should be introduced. He proposed using the brick programming tool Scratch (Scratch, 2013). At our department, we have used both Scratch and App Inventor (App Inventor, 2013) for students without prior programming experience. Physical education students created games in Scratch as an interface for an interactive shoe sole. The App Inventor was used as a prototyping tool in a Human Computer Interaction course (Nielsen & Majgaard, 2013).

Constructionistic learning promotes creative and innovative constructions in the real world. However, it does not involve articulating and analysing competences. Besides creating constructionistic learning process, we also wanted to promote the students’ analytic competences. We wanted the students to reflect on and articulate their design process. We believed the dialogue based on the academic theory and their programming experiences would reinforce the learning process. This is theoretically supported by Schön (2001) and Bateson (2000).

Knowledge evolves through active participation and reflection (Schön, 2001; Majgaard, 2011 and 2009). Active participation and the journey towards becoming a professional game-designer, are the key terms in creating games in the classroom. The knowledge achieved by the students was applied to actual designs of prototypes and to reflections on the process involved. Aspects of knowledge gained and applied is often difficult to put into words and can be described as tacit knowledge (Schön, 2001; Agyris, 1978).

The educational goals were to develop a new practice for the design of games. Knowledge-in-action is inherent in this practice and is difficult to make explicit in an adequate manner. It is, for example, difficult to explain how to use a hammer, or how to recognise a face in a large crowd. These are examples of actions that we spontaneously know how to perform in the actual situation.

The concept of knowledge-in-action alone is not sufficient in a learning process or in a field practice. This must be supported by more retrospective forms of reflection. In addition, the students reflect on their own learning strategy and they adjust to a given situation and context. It is a concept developed by Bateson (2000), and adapted for the current educational context (Gleerup, 2005). This type of reflection is deliberately used in teaching when students are asked to articulate what they have learned by designing a game and how to improve the learning strategy.
4. Learning potential based on the didactical approach

Our didactical approach was to use play, constructionism and reflection as a lever for the students’ learning process. Their views on professional games changed during the course and they developed respect for the bigger game productions. The new level of respect was based on the knowledge they gained about designing games. They were also able to point to game elements which did not function optimally. This expresses an ability to evaluate and analyse, which requires distance and perspective. Reflection-in-action and reflection-on-action are prerequisites for learning by creating games in the classroom. The students’ reflections alternated between reflection-in-action and reflection-on-action as part of the game design process. Reflection-in-action occurred when they were playing and developing games. They reflected-on-action when they evaluated and analysed the design process. The students took on different roles in the design process, e.g. game testers, developers and learners. Reflection-in-action and reflection-on-action are prerequisites for learning by creating games in the classroom.

The interplay between play, construction and reflection promoted several learning perspectives, highlighted below. First and foremost, the students changed their approach from a consumerist approach towards games to a participatory approach. They became creative, reflective and innovative contributors.

5. From digital native to becoming digital contributors and citizens

The students were between 4 and 10 years old when they played their first video games and the majority were between 5 and 6 years old. The games included Pinball, Super Mario, Pixiline, Magnus, and the Gnat and Mummy Trolls. At present half of the students highlight the bigger games such as World of Warcraft, GTA (Grand Theft Auto) or FIFA (European Football video game). The other half highlighted casual games such as Plants vs Zombies or Tetris. Virtually everyone mentioned that, at some point, they had played Counter Strike and Super Mario. Super Mario was even the inspiration for some of the game prototypes.

Today’s students are often regarded as digital citizens or digital natives, since computers have been a part of their lives from a very early age. Resnick (2009) argues that everybody should be able to make their own interactive games, stories, animations and simulations in order to fully participate and understand the digital community:

“..everyone has an opportunity to become a fully fluent contributor to today’s digital society.”
(Resnick 2009)

He argues that everybody should be able to programme at least on a basic level. In creating one’s own simple programmes, one gets a better understanding of the digital world and it becomes easier to influence the digital world. In Resnick’s perspective the students do not fully become digital citizens until they have started to make interactive digital contributions – in this case digital games. The students might be digital natives and digital consumers, since they had been using computers for play for most of their lives. But becoming a digital citizen requires a deeper understanding of the digital world and it requires that the students become digital contributors, see Figure 1.

Figure 1: Digital citizenship
The figure visualises the students’ voyage from digital native game consumers to becoming contributing game designers. The voyage gave them a new and more reflected view on playing games. When they play games in the future for pleasure or part of their study they will have gained a new and deeper insight on games. Our two didactical tools, constructionism and reflection, created a distance from the consumer role that allowed the students to become creative. And they transformed their game knowledge into new games.

6. The sandbox: gaming and learning simultaneously

How did we experience play in the classroom? In the classroom we took play and games very seriously. When the students suggested game ideas, such as lawnmowers vs. sheep, we seriously discussed gameplay strategies, balancing and programming details. The students explored and balanced the game play. They added new obstacles into the game to make it more interesting. Play created a space where it was okay to come up with quirky ideas, and where imagination and experimentation had its own framework. This framework formed a metaphorical sandbox. The sandbox was a kind of safe haven for the students where they could make mistakes and conduct experiments without being judged. It was ok for the students to add psychedelic monsters into the game or simulate a paranoid schizophrenic world view. The sandbox relates to Bateson’s theory of framing, where the learner ascribes or frames his context as being playful (Bateson, 2000:184). Gee (2003) also highlights sandboxes as safe havens that still look and feel like the real world, but with risks and dangers greatly mitigated.

The students played each other’s games. They gave feedback and became inspired by the other students’ games. There was a tendency for some students to make the intro play in their games too difficult for others to play. We believe one reason for this was because they were experienced, expert players in their own specific game. Feedback was often given to target the intro play appropriately for novice players.

Playing the games was a part of the design process. When the students added new code, the only way to test it was to play the game. The design process involved the students constantly alternating between playing and adding new code. The process actually pushed them into play and they were thereby pushed into the zone of proximal development (Vygotsky 1978). Their own homemade game became equivalent to a peer or a teacher. By entering the zone of proximal development, the students had the potential to learn more about programming and game development on their own. Often students will stop if things get too challenging. Play created a zone of proximal development which allowed the students to reach more of their potential on their own.

We believe that play created a sandbox for experimentation and that it was a motivational factor for the students. In this sandbox it was okay to make mistakes and have creative ideas. The students wanted to further solve programming problems, balance their game further and they thereby worked harder. In this way, the play became a lever for the students’ learning.

7. The constructionistic and innovative perspective

As part of the course, the students played specific games developed in GameMaker. The students learned about games by exploring games and they constructed games while exploring and optimising. They learned about specific game mechanics by watching the code and experimenting with new code structures. The students played the games while they were imitating and developing new versions of specific game functionality. This was done by “trial and error” learning. They used, e.g., some of the predefined actions, and afterwards they evaluated the consequences by playing the game. Subsequently, they could balance an action and thereby optimise the game strategies. This can be compared with Bateson’s learning 1 and 2, which are fundamental learning processes (Bateson, 2000). This also exemplifies how students learn while they are interacting and they are, in fact, using GameMaker as an object to think with. Papert (1993) discovered 20 years ago that programming tools were ideal as constructionistic learning tools, because the learners were
afforded an interactive object to think with. This also means that the students can learn more by themselves without teacher support.

Creativity and innovative designs: where does the inspiration come from? Pre-sensing, presence, and technological fascination. The students were inspired by their immediate environment, which required open-mindedness and presence. This is comparable to Scharmer’s (2000 & 2007) pre-sensing, where you are present in the moment and are not so easily affected by habits and conventions. In addition, they were inspired by the technological possibilities, such as specific game mechanics, another game, something they read in the newspaper, learned from a movie or an experience as simple as walking down the road. In the summer of 2011, there was a cucumber crisis where a lot of people got ill by eating cucumbers, and one student used this as a game idea. Another student was inspired by a contemporary movie called Cowboys and Aliens and developed a 2D game where a spaceship sucked up cows.

8. Reflection-in-games and reflection-on-games

The educational goals were to develop a new practice for the design of games. Knowledge-in-action is inherent in this practice and is difficult to make totally explicit. For example, it was difficult for the students to explain how to avoid obstacles while playing their homemade games, but they did it spontaneously in the actual situations. The concept of knowledge-in-action alone is not sufficient in a learning process or in a field practice. This must be supported by the more retrospective process of reflection we suggest the term – reflection-on-games. Reflection-on-games helps the students to articulate conceptual knowledge on game programming and game design. In the retrospective reflection process, their own experiences are connected to emerging conceptual knowledge. And conceptual knowledge is used in the professional communication amongst peers.

9. Professional reflection is divided into two parts:

Reflection-in-games involves a merging of multiple knowledge, experience and intuition during actions. Reflection-in-games occurs in the context of game design, when a student solves programming problems here and now in the game, e.g. a programmed character disappears off the screen instead of being stopped by the game’s virtual boundaries. This type of reflection is a here-and-now reflection, involving how to solve the here-and-now problems. This type of reflection might also occur during gameplay.

Reflection-on-games is the subsequent reflection and evaluation on the process that has occurred, and its potential consequences. It is precisely this type of reflection you want in the classroom as the evaluation of assignments and projects, for example, when the students analyse and present their prototypes. They reflect upon what happened in the design process, and how their experiences could be used in future designs. This type of reflection provides an overview of the design process. Furthermore, it offers an understanding of the design process and a holistic perspective. This type of reflection can be expressed in words and can be described as conceptual knowledge.

An example of reflection-on-games was a real live testing experience. The students gained insight into their own and others’ gaming experiences by testing the games on a target group. One of the tests took place in a 6th grade school class. Some of the students tested for usability problems and others tested for engaging user experiences. But what really surprised most of the students was the users’ approach. They had other game strategies and other ideas on what was meaningful in the games. The students really learned how difficult it was to predict user behaviour. They also recognised that a designer does not necessarily get the same gaming experience by playing, because he/she knows his/her own games too well.

Both reflection-in-games and reflection-on-games were applied during the course. It is in the interplay between these forms of reflection that the skilled game designer develops his potential, where innovative processes evolve and where students achieve a depth of learning.
Figure 2: Interplay between types of reflection

Reflection and playing games may appear to be polar opposite actions. In playing a game, one is present and not thinking about strategies for learning. However, reflection-in-action can easily occur in the play situation be (Schön, 1983). For example, in playing a strategy game, you are continually considering what alternatives provide for the best game performance. In a teaching situation, we can analyse and evaluate a specific game, e.g. game mechanics, fun factors, the pros and cons of strategic choices and ethical aspects. The process then changes from reflection-in-games to reflection-on-games. In this case, the students were transformed from game consumers into reflective learners and future game designers.

During the course, the students analysed a game from their childhood. A group of students chose Super Mario, and they used the tools from game design theory to analyse rules, gameplay, and dramaturgy (Fullerton, 2004). The learning goal was to transform the students’ own user perspectives on the games into professional and reflective perspectives. The assignment was rooted in something they already knew, and they evaluated it from a new angle with professional tools. This provides for meaningful learning processes. It exemplifies how learning processes can link a playful context and a professional game-design context. It is also an example of how games can provide a lever for the learning process.

In this interplay, it is also important to bring the students' game experiences into play in terms of game design. What makes a game interesting in the student's eyes, how can it be translated into new games and how does it fit with the theory?

10. Summary and Conclusion

In this article, we described how a group of engineering students set out as native consumers in the game world and journeyed towards becoming reflective designers. In the learning process, they needed to distance themselves from the consumer's role in order to process the new knowledge on game design, e.g., how to implement interesting game strategies. In addition, they read a lot of theory on what games are and what makes them interesting. To transform this knowledge into new games was hard work. In this process, they alternated dynamically between play, construction and reflection. The theory on games also gave them tools to analyse the potential and weaknesses of their own games. Their background as digital natives gave them insights and motivated them to create ideas in the design process. They became digital contributors and citizens of the game designers' community.

The didactics were organised in order to support play as a lever in the design process, constructionism, reflection-in-action and reflection-on-action. Playing games was a part of the design process, in which the students constantly alternated between playing the game and adding new code. Playing and developing games created a sandbox for experimentation, where it was okay to make mistakes and have creative ideas. We introduced the terms reflection-in-games and reflection-on-games. The terms are a further development of Shcön’s ideas in a context of game design. Reflection-in-games are a here and now reflection on game design, occurring when the student solves programming problems, plays, develops, balances and tests the game. Reflection-on-games is the subsequent reflection and evaluation on the game design process that has occurred. We wanted the students to explore and become aware of the iterative design process. Our teaching strategy was for the students to develop their creative and experimenting competences instead of us lecturing on programming commands and theory on methodology, etc. This required a programming tool with a “low floor” and a “high ceiling”. It also required structured activities in the classroom. The structuring activities
focused on making the iterative design phases visible. The activities also focused on retrospective reflections on how to balance their games, discussions on test results, etc. The constructionistic approach supported the following: exploring and optimising ways of learning; creativity and innovative designs; and the double perspective of simultaneous playing and learning. The reflection on action supported insights into others' gaming experiences and awareness of the design process.

In summary, we described the students' first voyages from being natives in the game world to becoming reflective designers. During the journey, they developed a reflective practice and an understanding of the profession they were entering. The article also shows a very dynamic and fruitful relationship between playing games and designing games. Furthermore, they develop the professional's professional humility and an understanding of the mission being developed in their profession.

In subsequent semesters on this engineering programme “Learning and Experience Technology”, the students will study about learning and design of digital systems for use in learning processes and, later, they will explore the serious games from both a learning and gaming perspective.

References

Designing Educational Games for Computer Programming: A holistic Framework

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Abstract: Computer science is continuously evolving during the past decades. This has also brought forth new knowledge that should be incorporated and new learning strategies must be adopted for the successful teaching of all sub-domains. For example, computer programming is a vital knowledge area within computer science with constantly changing curriculum and its teaching remains a difficult endeavour. On the other hand, students start from a very early age to interact with computers through games and other entertaining multimedia software. Therefore, they seem to be keen on environments with impressive special effects and graphical interfaces where they interact with the environment’s elements. In response, teachers are trying to connect computer programming learning with computer operations that students are familiar with, which does not include textual editors for programming lines of code with no other interaction. Educational games used in computer programming courses are considered to benefit learning, because they motivate students towards actively participating and interacting with the game’s activities. Thus, we have developed an educational multiplayer game that aims to further enhance computer programming education by addressing occurring problems. This process, however, requires proper planning during the design of educational games, and thus the availability of adequate guidelines that include all characteristics that should be incorporated in such games. This paper aims to introduce and elaborate on a holistic framework that has been constructed as a guide towards the development of this game. To this end, we study existing frameworks that have been proposed for the design of educational games and document features currently supported by educational games that teach computer programming. We conclusively propose the framework we have constructed for the design of our game. This framework can be used for the design of other computer programming-specific educational games and extended for other educational domains.

Keywords: computer programming; educational programming environments; educational games; holistic framework; learning process

1. Introduction

Computer science is one of the most fundamental courses worldwide, and the field seems to present a continuous and radical progress during the past decades due to the technology’s global advancements. This has also brought forth new knowledge that should be constantly incorporated in each course and new learning strategies should be adopted for their successful teaching. Studies have indicated that some sub-domains of computer science education, such as computer programming, present significant problems (e.g. lack of motivation, complex programming elements, lack of scaffolding etc) that hinder their successful teaching and learning (Lahtinen et al. 2005; Ragonis & Ben-Ari, 2005). Thus, there is an increasing need for employing technologies that can tackle these difficulties, incorporating the new knowledge and adopting new learning strategies to provide efficient and effective computer programming education.

Studies have indicated that three main categories of technologies exist that can address the aforementioned objective; these are educational programming environments, microworlds (Brusilovsky et al, 1997) and educational games (Gunter et al, 2008). Educational games have started evolving rapidly over the past few years, especially due to the fact that students today are being called the “Nintendo Generation” since they have become very familiarized with computer games in their everyday lives (Guzdial & Soloway, 2002). Additionally, educational games seem to be more apt for being used in computer programming education, since their provision of attractive graphical environments, interesting scenarios and high interactivity
motivate students to learn computer programming concepts through achieving goals within an environment they are already familiar with.

To this end, we have developed an educational game called CMX that aims to provide functionalities that help students to learn computer programming elements and teachers to organize their courses efficiently. The process of developing an educational game, however, requires taking into consideration multiple aspects that regard e.g. the technology, the pedagogy, the domain etc. This is facilitated by frameworks that serve to inform designers and developers of educational games on what elements should be supported.

The availability of such frameworks that provide adequate guidelines for designing and developing games for the educational domain is still considered to be a work in progress where more empirical studies are needed (Fisch, 2005; Dondlinger, 2007; Wong et al, 2007; de-Freitas, 2006). Even though a number of frameworks provide interesting concepts that should be taken into consideration, their practical application in designing educational games for specific learning domains and their corresponding evaluation and adaptation is still lacking.

This paper aims to present a holistic framework that has been constructed to guide the design of our game. The framework takes into consideration related work and is augmented with concepts that intend to support features that will provide a highly motivational and interesting virtual world for computer programming courses. The second section presents an overview of existing frameworks that have been proposed by published works for the design and development of domain-independent and computer programming-specific educational games as well as specific features that should be supported. The next section elaborates on our framework by presenting the methodology followed, a brief overview of the concepts included as well as a concise comparison of our framework with all identified existing frameworks. The paper concludes with a summary of the work done.

2. Related work

This section presents interesting frameworks proposed for the design of educational games in general. We continue to distinguish features supported by the most commonly known educational games that focus on computer programming education, following a top-down methodology approach.

2.1 Educational Games Frameworks

2.1.1 Four – dimensional framework

The Four-dimensional framework has been proposed by de Freitas & Jarvis (2006), as shown in Figure 1.
The work done and portrayed within the framework shows that this model comprises of four basic principles, as follows:

- **Context.** Each game is characterized by a specific context that will guide the scenarios as well as the ways students and teachers will interact with its features. During the context’s establishment, one must define characteristics such as required infrastructure, technical specifications, location of usage, type of game (e.g. role playing, multiplayer etc), activities to be performed etc.

- **Representation.** This concept refers to all representations that are required to be properly portrayed within the game. For example, each player needs to be represented by avatars that will have specific characteristics based on the context of the game. Additionally, the virtual world should represent interesting scenery that will be integrated with all the features of the game in a harmonized and meaningful way. Successful representation is vital for the increased motivation of students, since they need to be intrigued in order to want to learn by playing. An important metric that can determine this is the quality of the graphics employed during the representation, which needs to be high so that it can create better and more immersive simulations.

- **Learner.** This concept relates to all features corresponding to the learner within the game. Some of these include the ages of the students to be taught, their preferences, the availability and level of previous knowledge on the specific learning domain, our learning objectives regarding the game’s learning outcomes etc. Additionally, it is considered important by the relevant literature to try and promote learning through groups in educational games (Sandford, 2006), as collaborative learning is gradually being employed in education (Kayes et al., 2005).

- **Pedagogy.** The most important factor that distinguishes an educational game from a computer game is the pedagogical aspect, i.e. the fact that the entire game and its activities are developed in order to fulfil learning objectives and to result in learning outcomes. To this end, the development of such games should depend on the study and incorporation of learning strategies. These strategies later on determine how the game will be integrated into the learning process so that it will produce the desired outcomes.
representative examples of employed learning strategies are problem-based learning or experiential based learning, which allow a variety of pedagogical models for learning processes, especially when they use online technologies (Mayes & de Freitas, 2006). The pedagogies used should promote learning processes that will be constructivist and cognitive so that they will allow the creation of new knowledge by the students as well as their in depth comprehension of the taught material through active and collaborative participation. Additionally, learning processes have to be instructive and associative, that is they are required to progress in a logical manner and provide assistance when needed. Finally, collaborative learning when knowledge is exchanged through practice is also a feature that should be supported by learning processes within educational games (Mayes & de Freitas, 2004).

2.1.2 Conceptual framework

The second reviewed framework has been proposed by Yusoff et al. (2009) so as to provide a reference guide for the design of educational games, as shown in Figure 2.

**Figure 2:** Conceptual framework for educational games (Yusoff et al., 2009)

A brief overview of the framework’s features is provided as follows:

- **Capability.** This relates to the skills students should develop through their interaction with the game within the learning process. Such skills include analysis, recall, evaluation, effective execution of tasks, proper attitude and logical thinking.

- **Instructional content.** The game should be compliant with the educational material that students have to learn while interacting with it; therefore a thorough examination of the units of learning to be studied is essential and will determine the types of activities and assessment methods students will engage in during the game.

- **Intended learning outcomes.** Learning outcomes represent what goals students should be able to achieve once they successfully complete all assigned tasks. As it is depicted in Figure 2, a learning outcome is closely inter-connected with the determined capabilities and content. Different learning outcomes correspond to a particular set of capabilities and content.

- **Game attributes.** This concept includes all characteristics that aim to increase motivational and participatory learning. Such are scaffolding, i.e. assistance given to the students when needed; interaction, i.e. types of engagement and feedback required by the game towards the student and vice versa; learner control and sequence, i.e. level in which students can navigate across the virtual world based on assigned activities or on their own without any guidance, incremental learning; i.e. each learning outcome is achieved incrementally through the execution of a set of activities and not all in the end of the game; rewards, i.e. incentives provided to students that accomplish their goals as an acknowledgement of their successful endeavours and to students that are close to accomplishing them as a motivation to try more; authentic learning, i.e. the virtual world and the activities that will simulate an interesting and attractive environment with which students are already familiar, either from their real life or from their interactions with commonly used computer games.
Learning activity. Each activity plays an important role to the game and focuses on a specific set of tasks that need to be completed. It is important that all learning activities promote motivation so that students will remain interested and immersed in the game’s scenario. The design of an activity should take into consideration the learning outcomes that have to result once students successfully execute the given tasks and thus should allow the development of the intended capabilities as well as the comprehension of the corresponding materials. Lastly, the established game attributes will define the activity development.

Reflection. Students should be able reflect on their experience within the game and be provided with an overview of their progress when requested (Garris et al. 2002).

Games genre. This concept describes the type of the specific game that is to be developed. Specific genres are accompanied by different features so it is important to define from the design phase what type of an educational game this will be (e.g. strategy, open-world sandboxes, role-playing etc).

Game mechanics. This concept relates to the technicalities (e.g. management of resources, environment layout, database etc) that should be taken into consideration during the game’s development depending on the game’s genre, learning activities or instructional content.

Game achievement. The final concept refers to all the ways the game can represent a student’s achievement level and is also a significant metric of learning assessment. For example, the final scores each student has gathered along with any additional resources or “rewards” provide an overview of individual achievement and thus show to which level the intended learning outcomes were accomplished.

2.1.3 The Design, Play, and Experience Framework

The “Design, Play and Experience” framework aims to depict the relation between the designer and the player and explicitly demonstrate the concepts that correspond to each layer that is designed depending on the phase and user type. More specifically, the designer focuses on the “Design’ phase and has to initially identify the learning objectives that will guide the activities to be designed and that will be used as an evaluation metric once the development of the game is complete. Additionally, all other layers to be designed and shown in Figure 3 are initially based on the learning objectives and are later on configured and refined based on feedback from incremental and iterated engagement with the game, a process represented by the “Experience” phase. This is clearly depicted by the arrow connecting the “Experience” phase with the “Design” phase, expressing how continuous and practical engagement can affect the design phase of a next version of the game (Salen & Zimmerman, 2004).

![Figure 3: The Design, Play, and Experience Framework (Salen & Zimmerman, 2004)](image-url)
The “Play” phase represents the interaction of players with the game’s features. Thus, this phase is closely related to all characteristics of each individual player, such as knowledge background, skills etc. To this end, during the “Play” phase designers must take into consideration the target audience that will use the educational game and that will produce the different experiences during the “Experience” phase.

According to this framework, four different layers guide the design of an educational game. A brief overview of these layers is provided as follows:

- **Learning.** During the “Design” phase, the educational content that will be taught along with the pedagogical theory that will guide the learning process corresponds to the learning layer. In the “Play” phase, this refers to the actual teaching process, which is when students play the game. The “Experience” phase finally represents the learning that is accomplished through the teaching, and thus documents whether the set learning objectives have been achieved as learning outcomes.

- **Storytelling.** Storytelling provides valuable information during the game’s design that will guide the virtual world development as well as all the scenarios to be supported within the game. The designer sets the stage by designing the different characters to be included, the overall environment setting, the narrative and the different layouts that will structure the world (Rouse, 2001). Even though the designer sets the story, each player produces his individual storyline through the way he engages with the game’s activities during the “Play” phase. Similarly, the final player’s story as it will be created after the execution of all assigned tasks will represent the accomplished learning outcomes in the “Experience” phase.

- **Gameplay.** This layer includes all information regarding the players’ allowed actions within the game (Adams & Rollings, 2007). Initially, the designer has to define the specific mechanics of the game, such as the learning objectives, the challenges and allowed actions. Once these are integrated in the game, they are represented by the dynamics during game playing, i.e. all the different actions players take in the game that lead to individual pathways and interactions with the game’s features. The experience drawn from the play by each user is called an “affect” and represents all emotions players are left with after they are finished (e.g. satisfaction, disappointment, desire to try again etc).

- **User experience.** The final layer of the reviewed framework includes the most visual part of the game, which has to be as entertaining and accessible as possible in order to increase motivation and participation (Saltzman, 2000). The design phase supports the planning of the user interface and aims to provide multiple and easy to use interactivity opportunities during game playing. Finally, this will lead to experiences that engage students and accomplish in-depth comprehension of the learning material and successful skills development.

### 2.1.4 Experiential Gaming Model Framework

The experiential gaming model framework describes learning as a circular process that constructs cognitive schemas through activities within the game’s world (Kiili, 2005). The experiential gaming model framework aims to help game designers to understand the learning mechanism that should be employed in educational games, as shown in Figure 4. According to this model, the direct interactions and experiences players have with the game world create a circular learning process that includes all necessary steps to ensure successful learning objectives achievement. To this end, the model suggests that the activities that will be supported by an educational game should not only be cognitive but behavioural also. This way, players will behave within the activities of the game in a way that will allow them to build cognitive structures.
According to Kiili (2005), important elements of an educational game should be the scenario that will set up the learning objectives, the challenges students will have to face as well as the flow of the game. Additionally, the world of the game should allow active experimentation with the environment’s features so as to develop positive attitudes towards the game. Furthermore, feedback should be provided from the game during interaction that will allow students to reflect on their knowledge gained and to construct proper schemata and evaluate their own performance.

This experiential gaming model emphasizes that deep engagement of students in the learning process should be enabled in all of the game’s functionalities; students should always be learning while playing, whether they are chatting with other players or reading an educational material or executing a task or reflecting on their performance etc.

2.1.5 EFM: Model for Educational Game Design

A multi-dimensional model called EFM (Effective learning environment, Flow experience and Motivation) has been proposed regarding the proper design of educational games by Song & Zhang (2008), as shown in Figure 5. According to this model, an educational game’s environment should be able to support seven fundamental requirements that are highly interconnected with the other axes proposed in the model. These requirements include the availability of appropriate tools within the game as well as the sense of motivation along with the sense of direct engagement to activate students in the learning process. Moreover, the designers should ensure to avoid any possible distractions that could sway students’ attention away from learning and enable a constant sense of challenge that will allow them to go through all of the activities scheduled by the teachers and accomplished the clearly set educational goals.

The model also suggests that these seven dimensions of the requirements will determine the experiences within the game and their flow. Finally, the authors indicate four main strategy components that will stimulate motivation for students, namely “Interest”, “Goal”, “Feedback” and “Challenge”. The activities and experiences...
within the game’s world should be designed so as to enable all these four motivation strategies in order to create an effective educational game.

Figure 5: EFM: Model for Educational Game Design (Song and Zhang, 2008)

2.1.6 Educational Games Design Model Framework

The model proposed by Ibrahim & Jaafar (2009) includes three major factors that should be taken into consideration when designing educational games, as shown in Figure 6. The factors are game design, pedagogy and learning content modelling. Each of these is further analyzed within the model to provide analytical information on how to incorporate its features to the game.

Figure 6: Ibrahim’s and Jaafar’s Educational Games Design Model Framework (Ibrahim and Jaafar, 2009)
Initially, the authors suggest that during game design, the usability of the game should be ensured, and more specifically tested under the ISO 9241 usability standard (Pinelle and Wong, 2008). An educational game is considered usable when it provides satisfaction to its players, it is effective in achieving the goals set before playing and it is efficient in allowing consistent and responsive functionalities. Moreover, it is considered important to allow multimodal content in educational games (e.g. text, audio, videos, animation, graphics etc) as well as the ability for players to directly interact with this content and receive appropriate feedback. Finally, game design should also support the entertaining element of a computer game, which is essential (Prensky, 2001) because games should be fun to interact with even in educational settings. To this end, designers are expected to include functionalities that will allow teachers to set clear educational goals and activities that will challenge students during playing, will engage them in navigating through the game’s features by increasing their curiosity even though they will not know the outcome (Malone, 1980) and will boost their self-esteem.

Furthermore, the authors include the pedagogical factor in the design model, which suggests that the computer games should be designed according to the educational domain and incorporate proper learning strategies to ensure that the game will indeed result in the desired learning outcomes. More specifically, the model is drafted so as to support learning outcomes that belong within the three first levels of the Bloom Taxonomy, namely knowledge, comprehension and application (Ibrahim & Jaafar, 2009). These three levels of knowledge should be accommodated through appropriate theory availability and modules that motivate learners to reach the 3rd level of knowledge. Additionally, educational games designed according to this model should support self-learning and thus reflection mechanisms; these games allow students to teach themselves by playing, reading the learning materials and assess their own performance. Thus, the authors indicate that such games could be developed as web-based environments so that they can be accessed by learners at any time. The active role of learners in the educational games will increase their competences since traditional learning where knowledge is simply delivered will be replaced by a series of problem solving activities that will stimulate learners’ minds and allow them to learn how to solve problems by interacting with materials and tasks within the game. This calls for specific types of learning materials that allow self-learning and problem solving.

Therefore, it is important to also consider the last factor included in the design model, namely the learning content modelling. The content incorporated within the game should be available at specific parts of the game in order to ensure the proper solving of the given problem and thus result in the set learning outcomes. Moreover, features such as a syllabus, terms matching tools and scaffolding mechanisms would increase learners’ sense of security since they will mostly be learning on their own, with the teachers available only during lectures time to provide guidance.

2.2 Features in games teaching computer programming

We continue to study existing games that focus on the computer programming learning domain and distinguish specific features that need to be supported by future educational games.

2.2.1 The SCRATCH environment

The MIT Media Lab research group developed Scratch aiming to create an environment that would assist creative people to easily accomplish their goals. This aim is also depicted in Figure 7.
The Scratch environment was based on the above design principles and introduces computer programming to students of ages 10 to 18 (Resnick, 2007). Towards this goal, students can create programs, interactive stories and games through drag & drop tiles instead of writing lines of code, thus avoiding making syntax errors. Interaction and scenarios play an important role in this game as they intend to stimulate the interest of young students by engaging them in a series of attractive assignments. The availability of multiple characters (sprites), backgrounds, sounds and images motivate students to create their own animations and games, play on their own and share their creations with their classmates, as well as reflect their creations to others.

2.2.2 Educational games for computer programming

A thorough investigation was carried out on frameworks and models proposed for the design of educational games that have been specifically designed and developed to support computer programming education. During this research, we identified one architecture that is further analyzed and a list of important features that should be supported by educational games constructed for teaching computer programming concepts.

More specifically, the identified architecture shown in Figure 8 was proposed by Maragos & Grigoriadou (2005) for the design of intelligent educational games that aim to teach computer programming. This architecture was employed for the design and development of the educational game TALENT, which supports algorithmic if-statements and loops through interactive role-playing.

Figure 8: Architecture for Intelligent Educational Game (Maragos & Grigoriadou, 2005)
According to this model, the world of the game is constructed and can be changed through authoring tools by the teachers. These authoring tools should also allow the addition of pedagogies in the game’s environment, such as tutoring strategies that support successful learning. This is usually done via a pedagogical agent, which is represented as a character or a tool within the educational game. The agent usually intervenes in the game’s process and provides feedback whenever a student with a specific profile requires it.

Furthermore, the game supports multiple learner models that can be assessed according to each student’s specific performances and profiles. These models are built in accordance to the pedagogical goals the teachers set while they are constructing the game’s world and depending on the educational materials to be taught as well as the activities/ steps that the students have to go through.

All of the above components of the model suggested allow for great configuration rights by the teachers, thus providing abundant flexibility to create multiple different instances of the same game. Teachers can study their students’ behaviours and correspondingly adapt the game’s scenario, materials, activities, goals and desired outcomes.

Furthermore, we continue to identify the main features that should be supported by educational games designed and developed for computer programming courses. The work done is the combination of previous research (Malliarakis et al. 2012) and a more thorough overview of the educational games Catacombs (Barnes et al., 2008), Saving Sera (Barnes et al., 2008), EleMental (Chaffin et al., 2009), Prog & Play (Muratet et al., 2010), Robozzle (Li & Watson, 2011), Lightbot (Piteira & Haddad, 2011), Robocode (O’Kelly & Gibson, 2006), TALENT (Maragos & Grigoriadou, 2011), M.U.P.P.E.T.S. (Phelps et al., 2003), Wu’s Castle (Eagle & Barnes, 2009), Playlogo 3D (Paliokas et al, 2011) and Gidget (Lee & Ko, 2011). These educational games follow a “play-learn-improve-win” pattern during learning, a pedagogical aim that is similar to the one employed in Scratch and depicted in Figure 7.

According to the review carried out, the main features supported can be considered as requirements specification for future educational games’ design and development. A brief overview of the most commonly identified features is provided as follows:

- Multiplayer / Role – playing
- Interaction / Experimentation
- Collaboration
- Scaffolding
- Drag & drop lines of code
- Programming editor for writing lines of code
- Multiple choice questions
- Scenarios
- Compiler that allows interaction with errors
- Physical/ familiar metaphor
- Visualization of concepts
- Simplicity

Each game supports a different set of the features included in the list as well as of the features shown in the examined frameworks during their design. Thus, we have worked on developing a game that will include as many of these features and concepts as possible, while maintaining limited complexity of the environment.
3. Our framework

This section provides information regarding the design process of our CMX educational game that focuses on the education of the computer programming domain. The CMX educational game is a Massive Multiplayer Online Role-Playing Game (MMORPG) and aims to familiarize secondary school students that are novices to computer programming with concepts such as variables, if-statements, loops etc, and engage them in algorithmic logic. It is different than existing systems, since the game supports different functionalities for the student (player), the teacher (tutor), the administrators and other educational agents, according to each user type’s role in the game.

As shown in the following figure, tutors, administrators and users send their data in the central system, while the educational agents constantly send and receive information to and from the central system. Finally, the system in the figure represents the host of our educational game and sends information to the game regarding each virtual player as well as a different instance of the virtual world.

![Figure 9: MMORPG CMX data exchange](image)

It is essential to initiate the design of the game by studying its characteristics and defining generic metrics that will need to be instantiated based on the different user type. Therefore, we initially define a user-centric model for the design of educational games, as shown in Figure 10. Based on this model, the design phase takes into consideration each user type’s initial aspirations that motivate them to use the game, the specific targets they set to achieve through the game, the metrics that will determine the level in which the targets are achieved as well as the feedback provided to them by the system depending on the corresponding target.

These inter-connected concepts are different for each user type and therefore relate to different aspects of the game. For example, the game administrator’s aspirations can be the game’s and server’s problem-free operation and the corresponding targets can be the backup of the data produced, the frequent monitoring for possible malfunctions etc. Performance metrics could include the server’s database capacity, the cache memory capacity etc, while feedback that will indicate whether the server is working properly can comprise of error messages produced by the game (e.g. in case new data cannot be saved).

Similarly, a teacher’s aspirations can be the successful teaching of units on computer programming while the target can look like “at least three of the four game levels on loops will be achieved by all”. Thus, the set metrics can be each level’s and student’s score, log files from the game etc, while the feedback can be a report with the student’s progress at a given time/level.
Furthermore, a student’s aspiration can be to enjoy his time within the game, to distinguish himself through accomplishing the assigned tasks and to learn. Based on these aspirations they can set their individual or group targets across the overall learning objectives. Their performance metrics can be the score/resources they have gathered, how many times they have had to retry before writing lines of code correctly etc. Finally, feedback can be explanatory messages from the agents, introductory narrative or video that explains the scenario, errors in the program they’re writing etc.

This closely interconnected puzzle is shown in Figure 10 and provides a more abstract overview of the initial metrics taken into consideration during design phase, following a user-centric approach. This model takes the form of a puzzle since all user types need to be addressed equally and represent a different point of view of the game.

Figure 10: CMX Design Strategy Puzzle

The next step that will lead to the proper construction of our framework is the identification of the methodology our game will be based on. More specifically, as shown in Figure 11, students will initially engage in actions, which will in turn generate their desire for improvement through attractive scenarios. These actions will help students gain new knowledge regarding the targeted educational content and through collaborative activities, students will be able to produce the set learning outcomes. In the end, the learning objectives will be achieved after the game experience is properly evaluated.

Figure 11: Methodology steps of the CMX educational game

Finally, both aforementioned steps are reinforced from the review presented in the related work section. More specifically, based on the review of the existing frameworks that guide the design of educational games in general as well as of the features supported by educational games focused on computer programming education, we move on to propose an extended framework that includes the most commonly identified concepts as well as a series of sub-concepts that provide a more in-depth visualization of the steps to be followed during the design and development process. Based on this framework, which is shown in Figure 12, we have designed and developed an MMORPG educational game that aims to teach computer programming.
The CMX Design framework includes concepts that need to be represented within any educational game that aims to teach computer programming. It is abstract enough to be employed by future designers and developers and detailed enough to act as a solid guide without allowing many arbitraries. The most prominent concepts that define the game’s design are:

- **Infrastructure.** The design initiates with the establishment of the infrastructure architecture, the technical requirements specification as well as the user interface and concepts visualization design. The infrastructure will have to support simplicity and ease of use.

- **Learning objectives.** Designers will have to initially define learning objectives that the game will be required to successfully support. These objectives can include generic goals (e.g. more than 80% of the students will complete all game’s activities within the given deadline) or programming-specific goals (e.g. the 90% of the students will drag & drop correctly the lines of code regarding if statements). Additionally, students can also define their own goals depending on what they desire to achieve through their interaction with the game (e.g. “I have understood if statements so I want to complete all tasks related to loops”).

- **Pedagogy.** The game’s layout will strongly depend on the learning strategy to be employed during class as well as on the way the course will be organized (i.e. number of units of learning, educational material to be taught etc). For example, it is possible that the teacher will want to create a level per unit of learning, or merge specific units of learning into one game that will correspond to a certain set of learning objectives. Thus, it is essential to determine these features at an early stage.

- **Learning outcomes.** The determination of the learning outcomes is strongly inter-connected with the set learning objectives. Target outcomes can include the comprehension of the taught material, i.e. computer-programming concepts, such as variables declaration, if statements, loops etc, skills development, such as critical thinking, teamwork, leadership etc as well as interaction capabilities and engagement with innovative technologies and their features.
• User. A user in an advanced educational game can represent different types (e.g. student, teacher, administrator, agent), where each type signifies another aspect of the game’s functionalities, as already explained in the CMX design strategy puzzle. Additionally, the specific characteristics of each user need to be determined (e.g. age, prior knowledge, preferences etc) as well the aspirations that will drive the user’s interaction with the system (e.g. win the game-student, ensure problem free operation-administrator, instruct and assist students-teacher, guide and scaffold players-agent). Finally, each user will need to be able to reflect on the game experience for feedback gathering and future refinement of the game’s functionalities.

• Scenario. The game’s scenario should be thoroughly researched and planned out in order to produce an attractive and immersive virtual world (e.g. fighting arena, castle, forest etc) with interesting characters (e.g. wizards, robots, mentors, snowmen, prisoners etc) that are required to complete interim and final goals (e.g. save the princess, put the map’s pieces in their correct order, navigate through the tree etc). Designers have to also define what types of awards players will be granted with during the game, in order to increase their motivation to continue learning.

• Activities. The design and development of individual activities is essential and will result to the interested and active participation of students. It is important that students will be able to interact with the world’s elements and collaborate with others towards the achievement of all or some of the goals. Additionally, the environment should provide scaffolding mechanisms throughout all activities that will assist students during challenging tasks. Finally, a number of different ways in which students can contribute their knowledge should be included, since not all students learn better using the same techniques. Thus, an educational game should incorporate a programming editor, along with the ability for students to drag & drop lines of code as well as answer multiple choice questions.

The following table lists all features included in our proposed framework and depicts which features are supported by the corresponding layers of each of the seven frameworks studied during this research.

Table 1: Comparison of features supported by frameworks for educational games’ design

<table>
<thead>
<tr>
<th>CMX design framework</th>
<th>Four – dimensional framework</th>
<th>Conceptual framework</th>
<th>The Design, Play, and Experience Framework</th>
<th>Experiential Gaming Model Framework</th>
<th>EFM Model</th>
<th>Educationa l Games Design Model Framework</th>
<th>Architecture of Intelligent Educational Game</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning objectives</td>
<td>X (Learner)</td>
<td>X (Learning)</td>
<td>X (Situated learning objectives)</td>
<td>X (Authoring tools)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generic goals</td>
<td>X (Learner)</td>
<td>X (Learning)</td>
<td>X (Clear goals)</td>
<td>X (Goals)</td>
<td>X (Clear goals)</td>
<td></td>
<td></td>
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<tr>
<td>Goals set by students</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Domain-specific goals</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>X (Specific Goals)</td>
</tr>
<tr>
<td>Pedagogy</td>
<td>X (Pedagogy)</td>
<td></td>
<td>X (Pedagogy)</td>
<td>X (Pedagogy)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning strategy</td>
<td>X (Pedagogy)</td>
<td></td>
<td>X (Problem solving)</td>
<td>X (Pedagogy)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Course organization</td>
<td>X</td>
<td></td>
<td>X (Dimensions of flow experience)</td>
<td>X (Authoring tools)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning content</td>
<td>X (Instructional content)</td>
<td>X (Learning)</td>
<td>X (Design knowledge)</td>
<td>X (Learning content modeling)</td>
<td>X (Authoring tools)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Units of learning</td>
<td>X (Representation)</td>
<td>X (Game attributes)</td>
<td>X (Storytelling)</td>
<td>X (Established)</td>
<td>X (Authoring tools)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario</td>
<td>X</td>
<td></td>
<td>X (Frame story)</td>
<td></td>
<td></td>
<td></td>
<td>X (Authoring tools)</td>
</tr>
</tbody>
</table>
The concepts that were similar and included in the frameworks, even if they were not clearly represented by their models, were merged and included in our framework (e.g. the concepts within the Representation, Game attributes and Storytelling that referred to the game’s scenario are shown with the “Scenario” concept in the CMX framework). The compiler and the programming editor are suggested specifically for the computer programming domain; however, the framework includes a variety of concepts that allow its exploitation by other courses as well. This framework was employed during the design and consequently development of the MMORPG CMX game and was a valuable support, especially during the requirements and architecture specification processes.

4. Conclusions

The configuration of computer games so as they can be integrated in the educational domain has generated a new trend in technologies used for education called educational games. These games are considered to make students more comfortable in actively participating in learning since they are already familiar with the
graphical environment and scenarios and provide adequate features that help progressive computer programming teaching (e.g. scaffolding mechanisms, collaboration etc). This way, students not only comprehend the knowledge taught but they also learn to develop competences that will be useful to them in their future career endeavours (e.g. problem solving, critical thinking etc).

Nevertheless, in order to make sure that educational games include all necessary features that will ensure successful teaching and learning, it is essential that they are first designed properly. This indicates the need for designers of educational games to follow an analytical guide that depicts all concepts that should be taken into consideration. Thus, in this paper we have reviewed existing frameworks that describe such concepts and documented the features specified by the relevant literature. Furthermore, we studied educational games currently used in computer programming courses that do not indicate to have followed a specific framework for their design and listed the features supported.

As a result, we took into consideration all the above work done, and created the CMX design framework, which includes all characteristics identified as essential and was used to design and develop the MMORPG CMX educational game designed and developed for computer programming teaching. The CMX design framework is abstract enough that can be used as a reference framework for designing other educational games for computer programming courses and can also be extended in the future to fit other educational domains.

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Pervasive Learning – Using Games to Tear Down the Classroom Walls

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Abstract: Pervasive gaming is a new and emerging gaming genre where the physical and social aspects of the real world are integrated into the game and blends into the player’s everyday life. Given the nature of pervasive games, it may be possible to use that type of game as a tool to support learning in a university course by providing a gameplay where the students, by playing the game, expands the area of learning beyond the lecture hall and lectures and into the students everyday life. If this is possible, the area for learning will also become pervasive and be everywhere and anywhere at any time. To address this research area, a prototype of a playable pervasive game to support learning in university studies has been designed. This paper presents the experimental pervasive game Nuclear Mayhem and how the game was designed to be pervasive and support the curriculum of the course. Analysis of log files showed that 87% of the logins in the game client was done outside of the time period that was allocated to lectures and lab exercises and that logins where registered in all the 24 hours of a day. These numbers indicate that the game became pervasive and a part of the students/players everyday life. Interviews with the players indicate that they found the game exciting and fun to play, but that the academic tasks and riddles that they had to solve during the game were too easy to solve. The paper concludes that games such as Nuclear Mayhem are promising tools to support learning and transform the area for learning to become pervasive relative to the players everyday life and suggest improvements in the game for the next versions.

Keywords: Pervasive games, Education, Serious gaming, Pervasive learning, Game based learning, Dynamic storytelling

1. Introduction

Pervasive gaming is a gaming genre where the game is not confined to the virtual domain of the computer but extend the gaming experience out into the real world - be it on city streets, in the remote wilderness, or a living room. The players must interact with the environment and with real objects to achieve certain goals (game objectives and missions). In contrast to traditional computer games, which take place in limited and well-defined settings, pervasive games erase the boundaries between spatial, temporal, and social expansion (Lindt et al. 2007). Pervasive games are staged in reality and their main attractiveness is generated by using reality as a resource in the game (Waern et al. 2009).

It can be difficult to motivate students to devote enough time working with the academic material in the curriculum throughout the courses. This leads to students not having the necessary academic maturity and understanding of the course material when the exam is approaching, and in spite of “pressure reading” the last week(s) before the exam it is - for most of the students - not possible to obtain a sufficient understanding of the subject to be able to get a good grade in the course. It is desirable that students work much more smoothly with the subject matter throughout the course instead of just "burst reading" when the exam is approaching. A solution to this problem might be to expand the area for learning outside of the lecture hall to become pervasive and enable learning to happen anytime and anywhere, for the duration of the course.

Given the nature of pervasive games, being games where the players are in the game everywhere all the time for the whole duration of the game, such games may be useful as a tool and a platform to extend the area for learning beyond the lecture room and into the students everyday life in such a way that the area for learning becomes pervasive. The research question is therefore as follows: Can a pervasive game be used to expand the area for learning and awareness beyond the university classroom and into the students’ everyday life and enable learning to be anytime and anywhere?

To address this research question a playable prototype of a pervasive game to support university studies was designed (Nuclear Mayhem) and the game went parallel with the course it was designed to support. The
duration of the course, and thereby of *Nuclear Mayhem*, was nine weeks. The students had to complete the game within a given time limit to be allowed to attend the exam, and participation in the game was the only mandatory activity during the course. Apart from participation in the game, everything else was voluntary, including attending the lectures.

2. **Pervasive gaming – a definition**

The terms pervasive game and pervasive gaming are widely used on a lot of different types of games, toys and experiences (Magerkurth et al. 2005). However, the boundaries between pervasive games and other types of games are unclear and to determine if a game is pervasive or not is not always easy. This situation is made more difficult by the fact that the field, due to the many different definitions, is defined very broadly. The term pervasive game is so broadly defined that it becomes almost meaningless.

Some games are labelled as pervasive games because the players must interact with each other and with the environment around them and physically move to specific places in order to perform tasks within the game (Cheek et al. 2006, Lindt et al. 2007, Segatto et al. 2008, Smith et al. 2005). The game *SupaFly* is labelled a pervasive game because it can be played “anytime, anywhere” using pervasive technology (Jegers and Wiberg 2006). Some argue that pervasive games are played in the real world and not on computer screens (Jonsson and Waern 2008) and others argue that pervasive games enhance computer games by employing emergent pervasive technology (Lindt et al. 2007). One definition of pervasive games uses the metaphorical magic circle of play as its point of view (Montola 2005), another definition focuses on the technology used in the game (Laine and Sutinen 2011) and a third definition states that a pervasive game is a game that is played in physical space, and that the places players visit are given a new meaning by the game (Magnusson et al. 2011).

Different researchers approach pervasive games from different and varying perspectives, defining the term pervasive game based on the technology that enables the game to be played, or the game itself (Nieuwdorp 2007).

In addition to the different definitions of the term *Pervasive game* attempts have been made to clear up ambiguities by – instead of providing a definition of what pervasive games is – defining a conceptual framework *TeMPS* (Hong et al. 2010) to systematically characterize important aspects of this type of games. The main idea behind *TeMPS* is to provide a framework to help game designers understand and communicate about pervasive and social games.

The divergent understanding and definition of the term pervasive game, makes it clear that there is a need for a clear, strict and unambiguous definition of the term, however that is not the aim of this paper. This paper uses the following technologically independent definition of the term *pervasive game*:

*A pervasive game is a game that is pervasive relative to the player’s everyday life.*

For a game to be pervasive relative to the player’s everyday life, it has to be both spatially pervasive and temporally pervasive.

If the game is restricted to only a specific area, such as the university campus, the game is not spatially pervasive relative to the player’s everyday life because when the player leaves the university campus, he will no longer be a part of the game. For a game to be spatially pervasive the player has to be in the game no matter where he is located and game related actions, that needs the players attention, can occur regardless of where the player is located whether he is watching the news on TV at home or he is standing in queue at the mall.

The game also has to be stretched in time in order to be pervasive relative to the players everyday life, therefore it has to last long enough to enable the game to be a part of most events in a person’s everyday life.
If the game only last for 1-2 hours (or less), that timeframe makes it impossible for the game to be pervasive relative to the players everyday life since this timeframe only enables the game to be pervasive during a very small part of the players everyday life.

**Nuclear Mayhem** is a game that is pervasive relative to the player’s everyday life. The game last for 9 weeks and the players are a part of the game, no matter their physical location, 24/7 for the whole duration of the game.

## 3. Related work

There has been a lot of research on the use of games in education. Research has shown that games can be used to support teaching and learning (Jenkins et al. 2003) and that the use of games in education can improve skills in many different types of areas. Research done on how to use community-building mechanics in games to achieve learning in education suggests that social gaming has the potential to revolutionize the way students learn (Hicks 2010). In higher education, games can be used in three areas (Wang and Wu 2009):

- Games can be used instead of the mandatory/traditional assignments
- Games can be used to increase participation and motivation of the students
- Students may, by developing a game, learn about other topics such as for example game development, mathematics, physics, programming, game design and software development

**Nuclear Mayhem** tries to encompass all the three points above. There are no mandatory assignments or requirements in the course the game is designed to support except that the students must participate in the game and complete it within a specified deadline. Participation in the game is also intended to motivate students to spend more time on the subject, and as a part of the game, the player/student must develop a web-based game and as a result of this learn programming and game development.

Pervasive gaming is a research area that is becoming increasingly popular and more and more scientific articles are being published on this topic. Currently, pervasive gaming is mainly taking place within the research community and is not yet being widely used commercially. Research in pervasive gaming has so far been largely technology oriented where the motivation behind the development and design of the games has been to create games that are suitable as a platform for research on the technology one wants to explore. These include games like *Mobio Threat* (Segatto et al. 2008), *The Drop* (Smith et al. 2005), *Epidemic Menace* (Lindt et al. 2007) and *Capture the Flag* (Cheok et al. 2006) where the motivation mainly is to test and explore technologies and how technology can be applied to move games out in the real world.

Research on the use of pervasive games to support learning or education (serious gaming) is a very interesting research area where some research has been done. The pervasive game *The search for the professor* (Spikol et al. 2009) was designed to introduce social web technologies and to support team building for a university course to beginning media technology students. *The search for the professor* shows promise to be a useful tool but needs a clearer integration into the course work.

Some research has been done on how pervasive games can benefit from being game-mastered rather than be fully automatic (Jonsson and Waern 2008). When a game is to be used in education it is critical that the game is aligned with the curriculum of the courses (Monroy et al. 2011). To ensure the best possible coordination with the topics of the course and the course progress *Nuclear Mayhem* had to be game-mastered. The boundaries of play in pervasive games are ambiguous, forcing the players to interpret what is a part of the game or not. This interpretation process demands and develops creativity among the players that can facilitate cheating in emergent play situations. However, cheating in games is not necessarily an undesirable thing. If the game master and game facilitators manage to respond to this type of emergent game play in a correct and creative manner, this type of activity can be used as a driver to promote creative learning processes (Ejsing-Duun et al. 2013). This strategy was not formalized as a part of the game play in *Nuclear Mayhem*, but the
game story and the game plot in *Nuclear Mayhem* is flexible and dynamic enough to facilitate this type of creative learning processes provided that the activity is discovered and handled properly by the game master.

4. **Nuclear Mayhem**

*Nuclear Mayhem* is a prototype of a pervasive game developed to support university studies in Multimedia and Web-game technology at Nord-Trøndelag University College, Norway. The pervasive game, *Nuclear Mayhem*, supports the course by providing a gameplay that is strongly related to the course syllabus. To be successful in the game, the players have to understand and master the topics in the syllabus.

The game starts on the first day of the course and ends when the examination is conducted. During this period the players (students) are in the game 24/7 everywhere and anywhere, both when they are at the university taking classes, when they are at home in bed, out partying with friends or doing whatever students are doing in their leisure time.

The game engages in the player’s everyday life in many ways. Clues and tasks are found on Facebook, are sent by SMS to the player’s phone in the middle of the night, is a part of the cityscape in Steinkjer (for example, tags that are placed in shop windows - Figure 1), is a part of student life (some of the lecturers appear to have secret messages that players must obtain) and on the Internet (clues and tasks are spread across different websites that players need to find).

![Figure 1: A paper note with a game clue is placed in the window at a hair salon in the main street of Steinkjer](image)

Several of the tasks that are carried out by the players during the game give points. For those players who are keen to win the game, it is an important strategy to be the first to perform the various tasks. The players can at any time see how many points they have in the game high score list (Figure 2). When the game is finished, the three players with the most points will be awarded.
The relationship between *Nuclear Mayhem* and the teaching of the curriculum of the course is illustrated in Figure 3.

The top line represents the game *Nuclear Mayhem* and the bottom line represents the university course. The game and the course both start and end exactly at the same dates.

The course starts with a presentation of the curriculum of the course and information on how to register as a player in the game *Nuclear Mayhem*. The students are told that participation in the game and completing the game within a given time limit is mandatory to be allowed to take the exam. After this information, the teaching of the course begins with the curriculum of week 1.

To be able to complete level 1 in the game and register the secret code in the game client at the end of level (Figure 4), the student/player has to learn the topics that are taught in week 1 since the academic challenge in level 1 is directly related to this. Furthermore, the academic challenge at level 2 is directly related to what is discussed in lectures in week 2, the same for level 3/week 3, level 4/week 4 and so on.
Figure 4: Each plot ends with a secret code that has to be registered in the web-client.

The last two weeks of the course, the students will conduct the exam project, which is to develop a functioning web game. At the same time period the players in Nuclear Mayhem have been assigned a mission where they shall create a web game that will be used to distract a guard, and that they – when the game is ready – will inform the saboteur group about this by registering the game URL in the Nuclear Mayhem game client.

Registering the URL address in the game client completes the game. To succeed with Nuclear Mayhem’s main mission, the URL address must be registered within a given deadline, a deadline that coincides exactly with the deadline for submission of the exam project in the course (Figure 5 below).

Figure 5: The game client shows the countdown towards the deadline for both the game and the course.

This is the only time limit that exists in the game and the game client is reminding the players about this by displaying a timer that is counting down towards the deadline second by second.

5. Game Story

The game story was constructed from the ability to support the story by referring to real life events that had already occurred (reality hack), and the likelihood that something would happen related to the story that
would be referred to by the news media (newspapers, television) and would be possible to implement as a part of the game story or game plot while the game was in progress. The strategy behind this design choice was that the use of real life events would help to create awareness about the game and make the game more pervasive and the game story more “real”.

At the time, Iran’s alleged nuclear weapons program was often mentioned in the news. There had already been a number of different events that could be used to substantiate the game story (Dagbladet 2010, Nettavisen 2004, Today 2009), and the issue seemed to be so relevant that it was highly probable that one or more events could happen during the game, that would be featured in the news media and thereafter could be implemented in the game. On the basis of these considerations the background theme chosen for the game story was Iran’s nuclear program.

This means that all tasks in the game in one way or another are motivated by the game story. For example, in one of the plots the player has to find a code that is located in a shop window in Steinkjer (Figure 1). To find the code, the player must first find a number of other physical locations in Steinkjer. In the game story this action is explained/justified by the need to lead the player around at different locations in Steinkjer so that "someone" can observe the player to ensure that the player is not followed.

6. Participants

17 students were attending the University Course that Nuclear Mayhem is designed to support, and all of the students were male. The age distribution of the students was from 20 years to 45 years.

17 students started Nuclear Mayhem and of those students, 15 live in the city where the game takes place and two students had to commute. A total of 16 students completed the game and of those, 14 students took the exam (included the two students that had to commute).

None of the students had any previous experience with pervasive gaming.

7. Methods and procedure

The nature of a pervasive game such as Nuclear Mayhem that is designed to be played anywhere at any time in the players everyday setting, is such that it is practically impossible to use an ethnographic approach where we study and observe the players while they are playing the game. An ethnographic approach to register and capture the players’ interactions with the game and all the potential situations of game play, would require that the players were observed 24 hours a day, both in their private and professional life, for the whole duration of the game. Furthermore it is not possible to study the players’ interactions with the environment and the environments ubiquitous artefacts since those are not directly accessible (Jegers and Wiberg 2006).

Since an ethnographic method for evaluation is unsuitable, four other methods were used to overcome the methodological challenges:

- a questionnaire
- interview of selected individual players
- system logs of user activities
- observations made by game master during the game

The game was played during a 9 week period. In this period, all the activities that were done by the players via email, Web or SMS to interact with the game were logged. A questionnaire, with both open-ended questions with free-text answering and multiple-choice questions, was used to capture the player’s subjective opinions of the game. The data collection was done via a Web-based questionnaire that the players had to complete immediately after the game was completed.
The questionnaire dealt with topics such as participation in the teaching program, previous programming experience, the use of mobile devices, previous gaming experience, the types of games you usually play, how you played *Nuclear Mayhem*, what you liked or disliked, what motivated or demotivated you to participate in the game and how the game managed to support the course.

There are too few participants in the survey to have statistically significant results, but the answers still provide an indication of the players' attitudes and opinions. Based on the responses in the questionnaire five people were chosen for in-depth interviews. The subjects were chosen based on their attitude towards the game. Of those who were selected for interview, there were two persons with a *positive* attitude, one person who was *neutral* and two persons who were *negative* to the game.

The in depth interviews were conducted after the exam grade was set, and the interviewees were informed about this fact and that nothing they would say in the interview, whether it was positive or negative, would make any difference to their final grade.

The interviews dealt with the respondents' general attitude towards games and the game *Nuclear Mayhem* in particular, how they felt about the game, the experience of the individual game plots, suggestions for improvements, the use of reality and the real world as part of the game and specific and detailed questions about what they perceived as good or bad during the game.

8. Results and discussion
In the duration of *Nuclear Mayhem* the 16 players logged in at the game client a total of 610 times. Of those logins 80 of them where in the same time period as the lectures in the course (in the classroom or at the computer lab) and 530 logins were in the period where there were no lectures in the course (before or after lectures or at dates there were no lectures at all).

![Figure 6: The percentage distribution of logins in the game client within and outside of the time period allocated to lectures in the course](image)

87% of the logins that were made in the game client was outside the time period devoted to teaching the course. The fact that so much of the game client activity occurred outside the time allocated for lectures in the course, suggests that the game managed to expand the area for learning beyond the boundary of the lecture hall.

Analysis of log files also show that although the majority of logins occurred in the period from 0800-1600, players logged into the game client most of the 24 hours a day.
The fact that there was activity in the game client around the clock suggests that the game succeeded in becoming pervasive in relation to the player's everyday life in the period the game lasted.

There was only one deadline in the game (Figure 5) that players had to comply with and to get the best possible match between the teaching of the course and the game, the players had to play and complete the game as shown in Figure 3. Analysis of the log files indicate that not all players played the game as intended and this is illustrated in Figure 8.

The fact that some players did not play the game according to the planned schedule is unfortunate because those students are not getting the desired relationship between the game and the course and they will not get the same learning outcome of playing the game as those who complete the game as planned.

The use of a game story that is designed based on real events has certainly helped to reinforce the game story and make it more exciting and real. The use of real events, that was featured in newspapers and in news broadcast on TV while the game was in progress, as a part of the game, reinforced the game story, the game plot and created more awareness about the game.
Furthermore, the use of real life events in the game also increased the pervasiveness of the game. The fact that the players were “exposed” to the game story in situations where they were normally in a low level of awareness about the game, such as while they were watching the news broadcast in the evening in the comfort of their own home - and then the newscaster presents a segment strongly related to the game story, or while they were buying groceries at the marked - and then discovers that the front page of the newspapers in the newspaper stand are featuring a story that is directly connected to the game story. Such events happened several times in the duration of the game and this helped to raise the awareness and the pervasiveness of the game among the players. “I saw it on the news and then I knew that something was going to happen”, is a quote from one of the players that clearly illustrates this effect.

Table 1: Quotes from the interviewed players/students on the topic of the use of the real world and real world events as part of the game and the game plot

<table>
<thead>
<tr>
<th>Quote</th>
<th>Subject</th>
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<tbody>
<tr>
<td>It makes it all the more realistic ... or more real ...</td>
<td>A</td>
</tr>
<tr>
<td>For my part, I think it made it more real ... when you connect it to more realistic stuff so ... it increases the tension as well.</td>
<td></td>
</tr>
<tr>
<td>It was a good plot, there was a lot of work put in it.</td>
<td>B</td>
</tr>
<tr>
<td>It was good. It made it the more exciting ...</td>
<td></td>
</tr>
<tr>
<td>The story itself was well supported, it was well made, and the details were good.</td>
<td>C</td>
</tr>
<tr>
<td>It was exciting, it was. It increased the atmosphere of the game.</td>
<td></td>
</tr>
<tr>
<td>I think that was good because it made the story more believable. Being able to read it in the newspapers made it a bit more credible. Real.</td>
<td>D</td>
</tr>
<tr>
<td>... story was perhaps a little too serious ... and then it might be a bit difficult to take it seriously ... I think it might be good ... then it becomes a little more realistic ...</td>
<td>E</td>
</tr>
</tbody>
</table>

All the interviewed students were positive to the use of real events in the game, even those who did not like this type of game or were negative to the game. The only objection that was mentioned was a player who thought the game might be a bit too serious, but the same player also emphasized that this made the game more realistic.

The use of stories from real life, where real people have been killed or injured, as part of a game raises some ethical questions that one should reflect on. In Nuclear Mayhem it was referred to the real terror attacks and the liquidation of real people to create a game story and a game plot. Nevertheless, no one has reacted to this. None of the players have reacted or noted this as a problem and none of the academicians I have discussed this issue with had any objections. This may be because the story takes place in Iran, a country that is far from our everyday world. The mental distance among the players and other participants in the game, between their everyday life and the real events that are used in the game, is considerable which certainly helps to create a distance to the events that have been used in the game. If there had been participants with greater proximity to the events depicted in the game, for example students from Iran, then maybe the use of these events in the game would be perceived differently as more abusive and offending. This is an issue one should be aware of when using real life events to design a game story.

Whether the students/players experienced the game as fun to play or not, seems to depend on what kind of game they preferred initially. Those who are positive to this type of games experienced the game as very
funny, while those who do not like RPGs were negative to the game even if they thought the game was well made. However, most of the players had some experiences in the game which they thought were interesting or fun regardless of whether they were positive or negative to the game.

**Table 2:** Quotes from the interviewed players/students on the topic whether they experienced the game as fun game to play

<table>
<thead>
<tr>
<th>Quote</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>I think it was awesome</td>
<td>A</td>
</tr>
<tr>
<td>I liked it a lot</td>
<td></td>
</tr>
<tr>
<td>... I thought it was fun.</td>
<td></td>
</tr>
<tr>
<td>- Subject A</td>
<td></td>
</tr>
<tr>
<td>I don’t like this type of games.</td>
<td>B</td>
</tr>
<tr>
<td>... I have never had a taste for RPG games, and maybe this game it’s more like an RPG.</td>
<td></td>
</tr>
<tr>
<td>... It was very well made, but it was not for me.</td>
<td></td>
</tr>
<tr>
<td>- Subject B</td>
<td></td>
</tr>
<tr>
<td>... when you entered the code in the game client ...that was very exciting. It really was the highlight. That was fun.</td>
<td>C</td>
</tr>
<tr>
<td>- Subject C</td>
<td></td>
</tr>
<tr>
<td>... it was exciting to enter the code ... I knew it was correct but it was still ... hehe</td>
<td>D</td>
</tr>
<tr>
<td>... I would recommend next year students to participate in the game.</td>
<td></td>
</tr>
<tr>
<td>- Subject D</td>
<td></td>
</tr>
<tr>
<td>... my biggest motivation was to win the game.</td>
<td>E</td>
</tr>
<tr>
<td>- Subject E</td>
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</table>

Another factor that may have affect on the gaming experience is the fact that the prototype only had one way through the game that all the players had to follow, and that this could have lead to an experience of railroading (Jonsson and Waern 2008), but none of those interviewed mentioned this as a problem.

All interviewees mentioned that they got a learning benefit of participating in the game, but several of them pointed out that they felt they would have had a greater benefit with an ordinary arrangement of compulsory exercises. At the same time, several of the interviewees mentioned that their participation in the game resultet in them using more time trying to understand and review the programming code using the textbook than if they had not participated in the game.

**Table 3:** Quotes from the interviewed players/students on the topic of the learning benefits of participating in the game

<table>
<thead>
<tr>
<th>Quote</th>
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</thead>
<tbody>
<tr>
<td>... the academic assignments were too easy</td>
<td>A</td>
</tr>
<tr>
<td>... I knew that the assignments were taken directly from the textbook</td>
<td></td>
</tr>
<tr>
<td>- Subject A</td>
<td></td>
</tr>
<tr>
<td>... to solve the problems in the game I used the textbook to compare the programming code and I learned something by doing this</td>
<td>B</td>
</tr>
<tr>
<td>... I did not understand until later that the game levels were following the lectures.</td>
<td></td>
</tr>
<tr>
<td>... I think I would have learned more if there was a deadline on each level since it would then almost have been like a compulsory assignment that must be completed within a given time.</td>
<td></td>
</tr>
<tr>
<td>- Subject B</td>
<td></td>
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</tbody>
</table>
... participation in the game was a motivating factor for me to sit down and study the programming code. 

... by participating in the game, I’ve learned a lot about Flash. I did not know that there was something called pervasive gaming before I was involved in this, but now, I know what it is and what it entails.
- Subject C

... to solve the academic assignments in the game I opened the programming files and went through them step by step. Read the code bit by bit and used the examples in the textbook to compare and see what was altered.
- This debugging made it easier for me to understand the examples in the textbook.

... I have learned about ActionScript 3.0 by participating in the game. I did not know how to program before.
- Subject D

... I would say that I have learned some ActionScript 3.0 and also something about pervasive gaming by participating in the game.
- Subject E

The learning benefit each player got from participating in the game also appears to be dependent on their level of expertise. Hence it can be that each player would have a larger learning benefit with a more dynamic model that adapts the professional challenges to the player’s skills.

All players who finished the game managed to pass the exam.

9. Conclusion

This paper has presented the concept and the prototype of the pervasive experimental game Nuclear Mayhem and showed how the game is designed to support learning in university studies.

Participants in the game reported that they believe they gained a learning benefit from participating in the game. Since all of the students that completed the game also passed the exam, the learning outcome of the game is also indicated by the fact that the students were able to recall and use the learned material to solve a given problem (the exam project and the academic challenges on each level). However, there is still a need for a stronger connection between the game and the course in addition to better adapted academic challenges in the game relative to the individual players’ academic level.

An instrument in ensuring a better match between the progress of the game and the lectures in the course would be to attach a deadline to each of the seven codes and a requirement for when each code has to be registered in the game client. A deadline on each of the seven secret codes will be easy to implement in the game.

All of the players, including those who were negative to the game, mentioned that they experienced all or parts of the game as fun or motivational.

Nuclear Mayhem has shown that this type of game has the potential to expand the learning space towards being pervasive and facilitate pervasive learning, but to better evaluate the academic benefits of participation in the game there is a need to develop a model to measure the academic benefits of participation in this type of game in terms of the learning objectives in the course to identify the “how, when and where” learning is facilitated in the duration of the game.

References


