Computers & Education 52 (2009) 1–12

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Digital Game-Based Learning in high school Computer Science education: Impact on educational effectiveness and student motivation

Marina Papastergiou *

Department of Physical Education and Sport Science, University of Thessaly, Karyes, 42100 Trikala, Greece

ARTICLE INFO

Article history:
Received 7 September 2007
Received in revised form 10 June 2008
Accepted 11 June 2008

Keywords:
Interactive learning environments
Multimedia/hypermedia systems
Applications in subject areas
Secondary education
Gender studies

ABSTRACT

The aim of this study was to assess the learning effectiveness and motivational appeal of a computer game for learning computer memory concepts, which was designed according to the curricular objectives and the subject matter of the Greek high school Computer Science (CS) curriculum, as compared to a similar application, encompassing identical learning objectives and content but lacking the gaming aspect. The study also investigated potential gender differences in the game's learning effectiveness and motivational appeal. The sample was 88 students, who were randomly assigned to two groups, one of which used the gaming application (Group A, $N = 47$) and the other one the non-gaming one (Group B, $N = 41$). A Computer Memory Knowledge Test (CMKT) was used as the pretest and posttest. Students were also observed during the interventions. Furthermore, after the interventions, students' views on the application they had used were elicited through a feedback questionnaire. Data analyses showed that the gaming approach was both more effective in promoting students' knowledge of computer memory concepts and more motivational than the non-gaming approach. Despite boys' greater involvement with, liking of and experience in computer gaming, and their greater initial computer memory knowledge, the learning gains that boys and girls achieved through the use of the game did not differ significantly, and the game was found to be equally motivational for boys and girls. The results suggest that within high school CS, educational computer games can be exploited as effective and motivational learning environments, regardless of students' gender.

1. Introduction

Computer games (henceforth called 'games') have become an integral part of our social and cultural environment (Oblinger, 2004), and are particularly appealing to children and adolescents, for whom they constitute the most popular computer activity in the home (Downes, 1999; Harris, 1999; Mumtaz, 2001). A study on 7–16 years old students in the UK showed that most of them were regular domestic game players (McFarlane, Sparrowhawk, & Heald, 2002), whereas a more recent study (Papastergiou & Solomonidou, 2005) indicated that one of the main reasons for domestic internet use among Greek students aged 12–16 years old was online gaming. Games, thus, play a central role in young people's lives outside school holding a special fascination and provoking a deep sense of engagement in them (Facer, 2003; Kafai, 2001; Kirriemuir & McFarlane, 2004). Essential game characteristics that contribute to this engagement are challenge, fantasy and curiosity (Malone, 1980).

Young people's intrinsic motivation towards games contrasts with their often noted lack of interest in curricular contents (Prensky, 2003). In fact, the challenging world of games shapes students' cognitive abilities and expectations about learning, making scholastic content and practices seem tedious and meaningless (Facer, 2003; Prensky, 2003), and creating a dissonance between formal education and the digital, informal learning environments that students experience outside school (Downes, 1999; Mumtaz, 2001; Oblinger, 2004). However, the motivation of games could be combined with curricular contents into what Prensky (2003) calls 'Digital Game-Based Learning' (DGBL). Games that encompass educational objectives and subject matter are believed to hold the potential to render learning of academic subjects more learner-centered, easier, more enjoyable, more interesting, and, thus, more effective (Kafai, 2001; Malone, 1980; Prensky, 2001). Specifically, games constitute potentially powerful learning environments for a number of reasons (Oblinger, 2004): (a) they can support multi-sensory, active, experiential, problem-based learning, (b) they favour activation of prior knowledge given that players must use previously learned information in order to advance, (c) they provide immediate feedback enabling players to test hypotheses and learn

* Tel.: +30 2431 0 47069; fax: +30 2431 0 47042.
E-mail address: mpapas@uth.gr

0360-1315/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compedu.2008.06.004

from their actions, (d) they encompass opportunities for self-assessment through the mechanisms of scoring and reaching different levels, and (e) they increasingly become social environments involving communities of players. Apart from knowledge acquisition, game playing can also favour the development of various skills, such as critical thinking and problem-solving skills (e.g. McFarlane et al., 2002). For all those reasons, Prensky's (2001) assertion that game design methods and techniques should inform the design of educational software to be used in schools is increasingly gaining acceptance within the educational technology research community (Kirriemuir, 2002).

However, as pointed out by certain authors (Facer, 2003; Kafai, 2001; Kirriemuir, 2002; Kirriemuir, McFarlane, 2004) and indicated by the following overview of prior empirical research, although games are believed to be motivational and educationally effective, the empirical evidence to support this assumption is still limited and contradictory, particularly regarding the effectiveness of games for concrete educational purposes, given that prior studies have focused more on motivational aspects than on curricular content aspects and core academic benefits. In an overview of the instructional gaming literature, Randel, Morris, Wetzel, and Whitehill (1992) found that the reported results were equivocal regarding the differences between games and traditional teaching methods, with 38 studies reporting no differences, 27 studies favouring games and 3 studies favouring traditional methods. In a subsequent overview, Dempsey, Lucassen, and Rasmussen (1996) pointed out that in many studies specific learning outcomes were ignored. More recently, certain research projects, namely TEEM ('Teachers Evaluating Educational Multimedia', http://www.teem.org.uk/) and CGE ('Computer Games in Education', http://partners.becta.org.uk/index.php?section=rh&rid=13595), investigated the use of commercial games in schools, producing positive benefits mainly regarding skills development and motivation, whereas curricular-specific learning outcomes were rarely mentioned (Facer, 2003; Kirriemuir, 2002). Other studies and projects focused on games specifically designed for educational purposes, addressing their motivational impact, and, in certain cases, learning effectiveness. The E-GEMS ('Electronic Games for Education in Math and Science', http://www.cs.ubc.ca/nest/egems/) project demonstrated that games increased children's motivation and academic achievement within mathematics and science education in grades 4–8 (Klawe, 1999). Nevertheless, the use of a language and mathematics game by students aged 8–12 years old revealed that many students were unable to articulate the underlying mathematical concepts (Young & Upitis, 1999). In another study, Yu, Chang, Liu, and Chan (2002) report on the use of a game for high school English, focusing on students' preferences and satisfaction from the learning experience. Rosas et al. (2003) found that the use of games on portable devices led to improved motivation and learning outcomes compared to traditional teaching within primary school mathematics and reading, whereas a pilot evaluation of a mobile DGBL environment on animal behavior with children aged 11–12 years old showed that they were enthusiastic about the experience (Facer et al., 2004). Finally, Virvou, Katsionis, and Manos (2005) compared a virtual reality game to educational software lacking the gaming aspect, within primary school geography, reporting that the game was very motivating and that it helped the students retain or improve their knowledge.

Another issue is whether DGBL can be motivational and effective for all students. In particular, given that games have been traditionally considered a male-dominated domain (Cassell & Jenkins, 1998), both in terms of content (e.g. many games comprise combat and reflect gender stereotypes) and centrality in males' and females' lives (Facer, 2003), an interesting question is whether DGBL is equally appealing and effective for boys and girls. Prior research on domestic computer use has shown that games are more popular with boys, who are more frequent, intensive and experienced game players than girls, and more likely to participate in players' communities for the exchange of game-related resources (Cassell & Jenkins, 1998; Downes, 1999; Facer, 2003; Harris, 1999; Mumtaz, 2001). Consequently, boys develop greater familiarity with computing hardware and software, and greater computer confidence and ability (Cassell & Jenkins, 1998; Downes, 1999; Papastergiou, 2008).

Prior empirical research on gender issues in the educational use of games is limited and has so far revealed important gender differences in students' gaming practices and preferences, and equivocal findings regarding the impact of gender on the learning effectiveness of DGBL. Specifically, within the TEEM project, boys and girls preferred different kinds of games and also, boys played more games and for longer periods than girls (McFarlane et al., 2002). Within the E-GEMS project, boys and girls also showed different preferences towards the games used, and different levels of performance with boys making faster progress, although no significant gender differences were found in terms of achievement in the embedded subject matter (Klawe, 1999). However, in the study by Young and Upitis (1999), also commented in De Jean, Upitis, Koch, and Young (1999), although more girls than boys demonstrated interest in the game appreciating its female protagonist, more boys than girls concentrated on completing the game, developed strategies to share information, and successfully recognized the embedded mathematics.

The afore-presented overview of prior empirical research indicates several issues that need to be further investigated. Firstly, given the limited and equivocal prior findings on the learning effectiveness of DGBL, further empirical research within school settings is needed into the impact of DGBL on students, not only in terms of motivation, but also in terms of learning outcomes in relation to concrete curricular objectives within specific subject areas. Secondly, the majority of prior studies concern traditional, well-established scholastic disciplines (e.g. mathematics). The researcher's bibliographical searches concerning Computer Science (CS), her area of interest and a relatively new scholastic discipline, revealed a lack of empirical evidence on the learning of CS concepts through instructional gaming within school settings. Specifically, the prior studies found (e.g. Duplantis, MacGregor, Klawe, & Ng, 2002; Prayaga, 2005; Werner, Campe, & Denner, 2005) concerned learning of computer programming, and, hence, involved school students in programming games instead of learning through interacting with them. The use of DGBL for the learning of various CS concepts, which differs from the learning of practical programming skills, thus, warrants a field investigation. Thirdly, the greater part of prior research focuses on children, whereas the impact of DGBL on students during the critical time of adolescence has been less explored. Further research is needed especially concerning high school level, where the question of keeping students motivated in the learning process and maintaining their scholastic competence becomes more acute (Hagborg, 1992). Fourthly, most prior studies that include control groups compare DGBL to traditional teaching. However, such comparisons with human tutoring imply that games are meant to totally replace classroom practice instead of complementing it (Virvou et al., 2005). Furthermore, new modes of learning based on Information and Communication Technologies (ICT) have emerged in recent years and become increasingly used in schools. It should, thus, be investigated whether DGBL is motivational and effective with students not only compared to traditional educational practices, but also compared to those modes. Finally, as girls increasingly use games (Prensky, 2003), further investigation of gender differences in the motivational impact and mainly the learning effectiveness of DGBL is needed, within various social and cultural contexts, given that the few recent empirical studies that have addressed the issue yielded contradictory findings, and were based only within the British and North American contexts.

The study presented in this paper attempts to fill in the afore-mentioned gaps in the research literature. The study aimed at assessing the learning effectiveness and motivational appeal of a game for learning computer memory concepts, which was designed on the basis of specific curricular objectives and subject matter pertaining to the Greek high school CS curriculum, as compared to a similar application in the form of a website, encompassing identical learning objectives and content but lacking the gaming aspect. Furthermore, the study aimed at investigating potential differences in the game's learning effectiveness and motivational appeal as a function of students' gender.

The study is unique in that it investigates the use of a game within real school settings for the purpose of teaching regular curricular CS content, other than programming, at high school level, while also comparing DGBL to another form of ICT-based learning and examining relevant gender issues. The study can further our understanding of the potential of DGBL. Specifically, it can help us learn whether educational games can be effective in promoting acquisition of domain knowledge and student engagement in the learning process within scholastic CS courses. In addition, it can provide insight into whether the impact of DGBL on students in terms of CS achievement and motivational appeal presents any differences between boys and girls.

2. Method

2.1. Research design

The study compared two educational applications on computer memory concepts. The two applications were identical in terms of embedded learning objectives and learning material, and differed only in that one followed a gaming approach, whereas the other did not. Any differences in learning outcomes and appeal to students between the two applications could, thus, be attributed to the gaming factor.

The students that participated in the study were assigned to two groups, one of which used the gaming application (Group A) and the other one used the non-gaming application (Group B). The study followed a pretest/posttest experimental design, taking before and after measures of each group, in order to explore the effects of type of application used (gaming, non-gaming) on students' achievement as measured by a knowledge test on computer memory concepts. Furthermore, after the completion of the interventions, students' views on various aspects of the application that they had used were elicited through a feedback questionnaire, and the effects of type of application on those views were explored. Students' gender served as a moderating variable.

Based on the overview of the research literature, the hypotheses of the study were formulated as follows:

I. The students of Group A would exhibit significantly greater achievement in terms of computer memory knowledge than those of Group B.
II. The students of Group A would form significantly more positive views on the application used compared to those of Group B.
III. Within Group A, boys would exhibit significantly greater achievement in terms of computer memory knowledge than girls, whereas within Group B the respective difference would not be significant.
IV. Within Group A, boys would exhibit significantly more positive views on the application used than girls, whereas within Group B the respective difference would not be significant.

2.2. Participants

The research was conducted in two randomly selected high schools located in Trikala, a typical town of central Greece. The sample were 88 students, 46 boys and 42 girls, aged 16–17 years old [mean (M) = 16.58, standard deviation (SD) = 0.50]. The students were attending the second grade and had been taught the same subject matter relevant to computer memory according to the Greek scholastic CS curriculum. They also possessed basic computer skills (e.g. Web browsing skills), which form part of this curriculum. Students had not previously used any educational software at school before. In each of the selected schools, all second grade students attending the course 'Computer Science and Computer Applications' served as subjects for the investigation. Specifically, in each school, participants were randomly assigned by intact classes to one of two groups (Group A and Group B). In total, six classes participated, three using the gaming application and three using the non-gaming one. Table 1 shows the distribution of the participants according to gender and intervention group.

2.3. Materials

Two similar applications constructed by the researcher were used in the study: (a) a gaming one called LearnMem1, and (b) a non-gaming one called LearnMem2. In the design of both, it was intended that the user interface be simple and intuitive and that navigation be as easy as possible so that students easily find their way around, without the need of any particular written instructions or technical skills.

2.3.1. Gaming application

LearnMem1 is a game conforming to the Greek high school CS curriculum and aiming at introducing students to basic computer memory concepts. The objectives of the application are that students learn about (Giakoumakis, Gyrtis, Belesiotis, Xynos, & Stergiopoulou-Kalantzi, 2002; Papakonstantinou, Tsanakas, Kozyris, Manousopoulou, & Matzakos, 1999): (a) the main parts of a computer's memory system,

Table 1
Distribution of participants according to gender and intervention group

	Group A	Group B	Total
Boys	26	20	46
Girls	21	21	42
Total	47	41	88

their role and utility, (b) the main attributes that differentiate the various memory units, (c) the organization of information within a memory unit, (d) the processes of information exchange with a memory unit, and (e) the hierarchical organization of computer memory. The learning material comprised in the application includes the following main topics: (1) the memory subsystem of a computer system, (2) read and write operations to a memory unit, (3) attributes of memory units (access time, storage capacity, storage cost), (4) role and utility of the main memory, (5) organization of and access to the main memory, (6) ROM memory and its utility, (7) role and utility of the cache memory, (8) role and utility of the secondary memory, (9) hard disks, (10) compact disks, (11) other secondary memory units, (12) comparison between the main memory and the secondary memory, (13) memory hierarchy, (14) differences among the various memory units of a computer system.

In the design of the game, the following elements that promote student involvement within an instructional gaming environment were adopted (Malone, 1980; Prensky, 2001): (a) rules, (b) clear but challenging goals, (c) a fantasy linked to the student activity, (d) progressive difficulty levels, (e) interaction and high degree of student control, (f) uncertain outcomes, and (g) immediate and constructive feedback. Furthermore, it was intended that the game be neither too complicated nor too simple with respect to students' existing knowledge with a view to evoke their curiosity and motivation (Malone, 1980). The traditional drawbacks of games, namely violence and gender bias, were avoided (e.g. the player character is non gender-specific with a view to be appealing to both boys and girls). However, the following practical limitations were also taken into account: (a) the game should be runnable on the outdated computing hardware of school computer laboratories, (b) the game should be easy to learn and should take about two hours to complete given that within the very tight timetable of the Greek high school, where CS is taught two hours weekly, the researcher would be allocated two hours per class for the experiment, and (c) the game development should not be time-consuming given that it would be undertaken by a single person (the researcher) with restricted time. Those constraints influenced the design of the game as follows: (a) the realistic but 'heavy' three-dimensional (3D) graphics were avoided, (b) the overall complexity was kept relatively low and the plot relatively simple.

LearnMem1 encourages active learning within an environment that combines access to hypermedia learning material, assembled in the form of webpages, with game playing. While navigating within the game environment, the student has the opportunity to search and discover information, to engage in problem-solving, to think hard about the concepts presented in the learning material and to test his/her understanding of those concepts.

More specifically, LearnMem1 is structured around three rooms in the form of mazes, which comprise hypermedia learning material and relevant questions of progressive levels of difficulty. Within each room, the student has to solve a number of problems which are presented to him/her in the form of true/false and multiple-choice questions (Fig. 1). The learning material (Fig. 2) encompasses texts, images, graphics and interactive animations relevant to various computer memory concepts. To successfully complete the game, the student has to accomplish the mission of reaching and collecting a termination flag in each room. The student is initially placed in the first room, where he/she assumes the role of a hero. Within each room, the hero should move towards the termination flag, successfully negotiating the various obstacles (e.g. doors to be opened, walls to be blasted by the setting off of bombs, moving robots to escape from) that he/she encounters, and should correctly answer all the questions posed to him/her and get the relevant points in order to obtain the flag, which will grant him/her the right to continue to the next room. Within each room, there are various 'information points', through which, the student can access parts of the learning material, which can help him/her understand the topics of the room's questions. Furthermore, in each room, there is the 'golden book' containing all the learning material that the student has access to and a navigation menu for this material. The

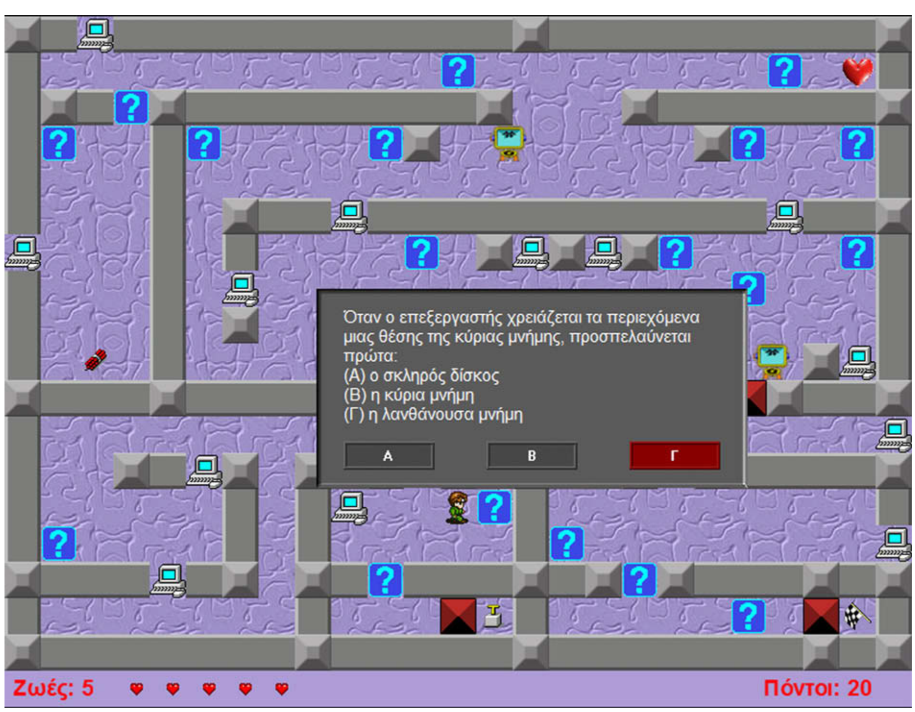

Fig. 1. Example of a room and a question.

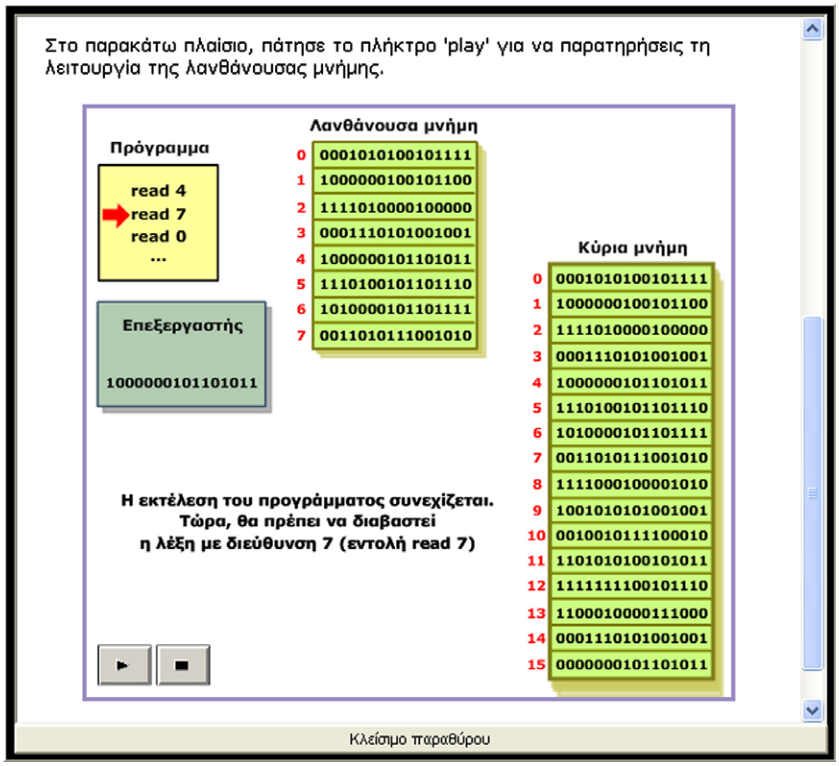

Fig. 2. Part of the learning material.

student can access the 'information points' and the 'golden book' in any order he/she wishes, provided that an obstacle does not block his/her course. The game also comprises background music and various sound effects on specific events.

Upon entering the game, the student has a number of lives and zero points. Each time the student answers a question within a room, he/she receives explanatory feedback regarding his/her response. In case of an erroneous answer, the number of lives decreases by one and the application provides the student with an explanation or a hint that can help him/her to find the correct answer. This mechanism was adopted to encourage a 'read, think and try approach' instead of a dumb 'trial and failure approach' (Natvig & Line, 2004). The students' number of remaining lives and current score are continuously displayed, so that he/she gets immediate feedback regarding his/her progress in the game. Furthermore, within a room, depending on the students' answers and actions, the student has the chance to collect special objects that endow him/her with bonus points and extra lives. When all his/her lives are lost, the student loses and the game terminates. In this case, the student can either stop playing or resume the game starting from the last room that he/she had managed to reach during the previous run of the game.

The game runs under Microsoft Windows 2000/XP and was developed using the game creation tool Game Maker 6.0 (http://www.gamemaker.nl/), following the relevant tutorial on maze game creation (Overmars, 2004), in combination with software for webpage creation, image processing and animation creation.

2.3.2. Non-gaming application

LearnMem2 is an educational website on computer memory. Its learning objectives and content are identical to those of LearnMem1. LearnMem2 comprises three thematic units, each consisting of learning material and an interactive quiz, and corresponding to a respective room of LearnMem1. Specifically, each thematic unit contains exactly the same webpages of learning material as the respective room of the game. This learning material is divided into subunits, each accessible through a navigation hyperlink and corresponding to an 'information point' of the respective room. Thus, the subunits function as the 'information points' of the game, and the thematic unit with its navigation menu (Fig. 3) as the 'golden' book of the game. Furthermore, the interactive quiz of each thematic unit regroups the questions of the respective room of the game (Fig. 4). The same progressive levels of difficulty as in LearnMem1 are maintained.

The student is initially directed to the first thematic unit when he/she can interact with the learning material and take the respective quiz. After having successfully answered to the questions of the quiz, he/she can move to the next thematic unit. The student should complete all thematic units and successfully answer all quizzes. Thus, the basic sequencing of the learning material and questions, and the chunking of the learning material, is the same as in LearnMem1. Upon entering the website, the student has a number of trial chances (the equivalent to the 'lives' of the game) and zero points. In case of a correct answer to a question, the student's score increases, whereas in case of an erroneous answer, he/she loses a trial chance. If the number of trial chances reaches zero, the student is forced to exit. In this case, he/she can either stop or re-enter the website. The feedback provided to the student (e.g. hints, explanations), when he/she chooses a correct or a wrong answer to a specific question, is exactly the same as in the game. Thus, the basic scoring and feedback mechanisms of LearnMem2 are similar to those of LearnMem1. Furthermore, as in LearnMem1, the student can view his/her number of remaining trial chances and current score.

LearnMem2 was developed using Active Server Pages (ASP) programming as well as software for webpage creation, image processing and animation creation.

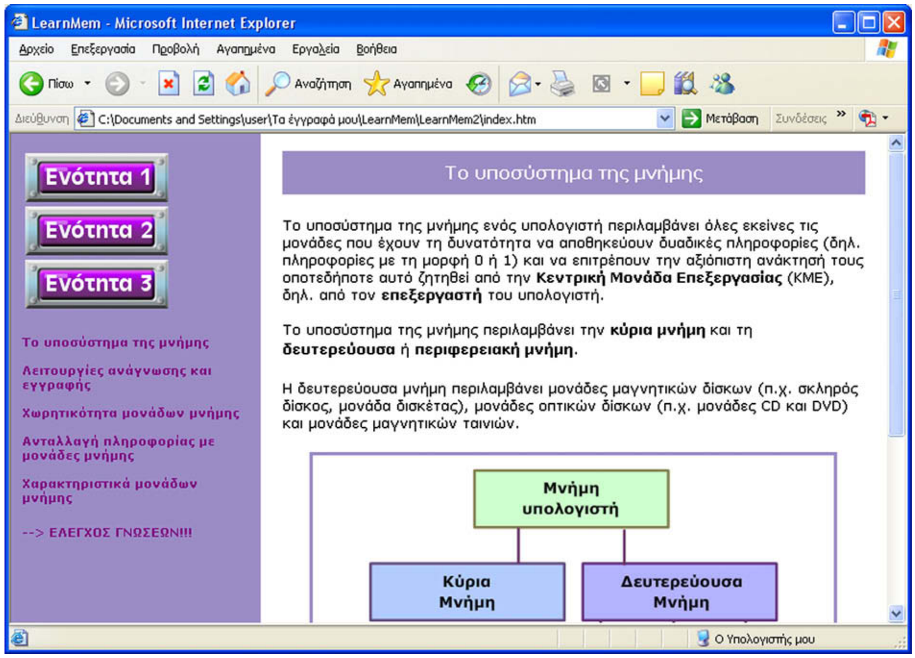

Fig. 3. Thematic unit with part of the learning material.

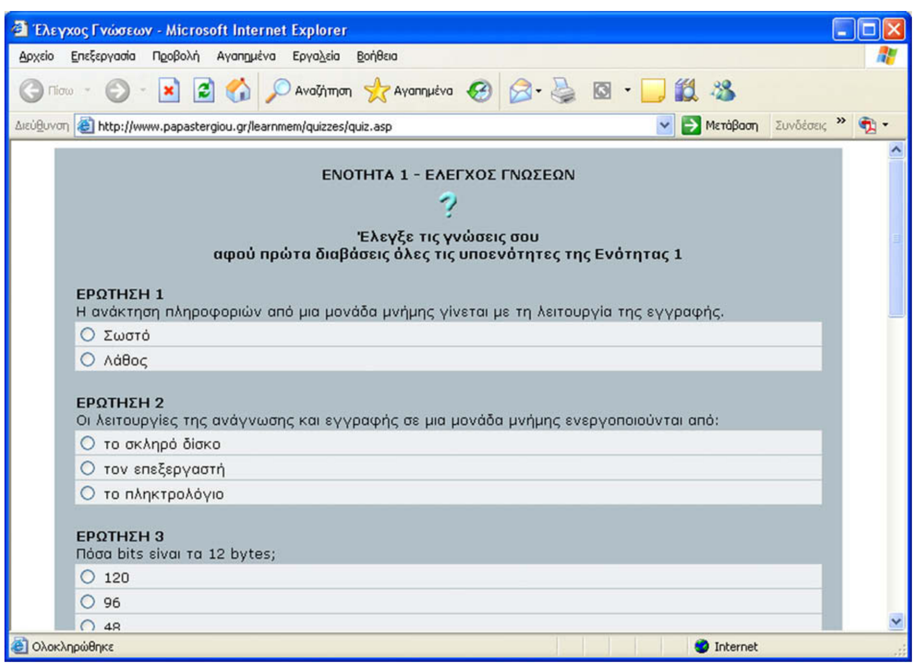

Fig. 4. Example of a quiz.

2.4. Instruments

For the purposes of the investigation, three paper-based questionnaires were constructed by the researcher: (a) a pretest questionnaire consisting of two parts (biographical variables, knowledge test on computer memory concepts), (b) a posttest questionnaire consisting of a knowledge test on computer memory concepts, and (c) a posttest feedback questionnaire.

The first part of the pretest questionnaire elicited the following biographical data: students' gender, age, average school grade, frequency of computer use, frequency of computer gaming, liking of computer games, computer experience and computer gaming experience. In particular, students were asked to note their gender and age as well as their average school grade in the previous scholastic year. Through two closed questions, they were also asked to specify on a 4-point scale (1 = 'never', 2 = 'several times per month', 3 = 'several times per week', 4 = 'everyday') how often: (a) they used a computer outside school, and (b) they played computer games outside school. Finally, they were

Table 2
Structure of the CMKT questionnaire

Question	Topic of the question
Q1	Read and write operations to a memory unit
Q2, Q3, Q6	Information exchange with a memory unit
Q4, Q7	Attributes of memory units
Q5	The memory subsystem of a computer
Q8, Q9	Storage capacity of memory units
Q10, Q12	Characteristics of the main memory
Q11, Q14	Role and utility of the main memory
Q13	Implementation of the main memory
Q15, Q16	Organization of the main memory
Q17	Access to the main memory
Q18	ROM memory and its utility
Q19, Q22	Role and utility of the cache memory
Q20	Comparison between the main and the secondary memory
Q21	Implementation of the cache memory
Q23, Q24	Access to the hard disk
Q25, Q27, Q28	Types of compact disks
Q26, Q29	Magnetic tapes and floppy disks
Q30	Differences among the various memory units of a computer

asked to specify on a 5-point scale (1 = 'not at all', 2 = 'a little', 3 = 'quite a lot', 4 = 'a lot', 5 = 'very much') their: (a) liking of computer games, (b) computer experience, and (c) computer gaming experience.

The second part of the pretest questionnaire was aimed at assessing students' knowledge of computer memory concepts prior to the beginning of the interventions. It consisted of a Computer Memory Knowledge Test (CMKT), which was constructed by the researcher and examined as to its content validity by a panel of experienced high school CS teachers. The CMKT comprised 30 true/false and multiple-choice questions on computer memory, derived from the subject matter of the Greek high school CS curriculum. All the informational content that a student would need to study in order to be able to answer to those questions was comprised in the learning material of both LearnMem1 and LearnMem2. However, the CMKT questions were not identical to any of the questions comprised in those applications. The structure of the questionnaire is presented in Table 2.

The first posttest questionnaire was targeted at measuring students' knowledge of computer memory concepts after the completion of the interventions, and consisted of 30 questions of the CMKT, except that their ordering was different than in the pretest.

The second posttest questionnaire consisted of two parts, and elicited both quantitative and qualitative data. The first part was aimed at assessing students' views on various attributes of the application that they had used, and comprised 12 items that explored four dimensions: (a) overall appeal, (b) quality of the user interface, (c) accessibility of the contained learning material and questions, and (d) perceived educational value. Specifically, through a series of closed questions, students were asked to rate on a 5-point scale (1 = 'not at all', 2 = 'a little', 3 = 'quite a lot', 4 = 'a lot', 5 = 'very much') the degree to which they found that the application: (1) was interesting, (2) was enjoyable, (3) was engaging, (4) was simple to use, (5) was easy to navigate, (6) comprised satisfactory graphics, (7) comprised subject matter easy to understand, (8) comprised questions easy to answer, (9) was useful, (10) was conducive to learning about computer memory, (11) was conducive to the understanding of computer memory concepts, (12) was preferable to traditional teaching within CS courses. The first of the afore-mentioned dimensions was explored through items 1–3, the second through items 4–6, the third through items 7 and 8, and the fourth through items 9–12.

The second part elicited, through open-ended questions, students' generic views on the use of educational games and websites at school, students' eventual proposals for the improvement of the specific application that they had used, and their appraisal of the overall experience of having used it within the scholastic CS course.

2.5. Procedure

Official leave to conduct the research in the scholastic year 2006–2007 was granted to the researcher by the Directorate of Secondary Education of Trikala. In each of the selected schools, initially, all second grade students attending the course 'Computer Science and Computer Applications' completed the pretest questionnaire, anonymously, in their respective classrooms, in the presence of the researcher.

The subsequent week, in each of the selected schools, the students of the selected classes interacted individually (each student seated at a personal computer) with their respective application (the students of Group A with LearnMem1 and those of Group B with LearnMem2), in the school computer laboratory, one class at a time, for two consecutive school hours, in the presence of the researcher and the CS teachers of the school. Prior to their actual interaction with the application, the students were given brief oral instructions on its use by the researcher. Throughout the interventions, the researcher also observed students' interaction with the applications. The CS teachers were present in order to provide procedural help to the students, without, however, being actively involved. During the interventions, the sound of the game was disabled due to the lack of headphones, which also eliminated potential biasing effects against the website that did not comprise any sound.

After the completion of the interventions, in a subsequent teaching hour, the students of the selected classes completed the two posttest questionnaires (the CMKT followed by the feedback questionnaire), anonymously, in their classrooms, in the presence of the researcher. The students did not receive any other form of instruction on computer memory during the time period between the pretest and the posttest.

The time intervals needed for the completion of the questionnaires were approximately 35 min for the pretest, 30 min for the first posttest and 15 min for the second posttest. For the matching of the pretest and posttest questionnaires, pseudonyms that the researcher had

Table 3
Comparison of the two groups as to biographical variables

Variable	Group A		Group B	
	M	SD	M	SD
Age	16.57	0.50	16.59	0.50
Average school grade	18.30	1.55	18.01	1.70
Frequency of computer use	3.09	1.02	3.12	0.98
Frequency of computer gaming	2.60	0.90	2.66	0.88
Liking of computer games	3.47	1.20	3.49	1.12
Computer experience	3.32	1.02	3.29	1.01
Computer gaming experience	3.40	1.15	3.32	1.08

asked the students to adopt and note down on their questionnaires were used. Students that were present for the pretest but absent from the posttest or vice-versa were excluded from the data analyses.

2.6. Data analysis

To investigate potential initial differences between Group A and Group B as to the biographical variables of the study, the following analyses were performed: (a) a χ^2 test for independence, with Yates' correction for continuity for 2×2 tables, compared the gender composition of the two groups, (b) one-way between-groups analyses of variance (ANOVAs) compared the two groups as to the rest of the biographical variables (age, average school grade, etc.). Potential gender differences as to the biographical variables related to computer use and computer gaming were also explored through one-way between-groups ANOVAs, with gender serving as the independent variable.

In each of the CMKTs (pretest and posttest), the student's number of correct answers was considered as his/her score in the respective test. Possible scores in each test, thus, ranged from 0 to 30 points. A 2×2 between-groups analysis of covariance (ANCOVA) was conducted to assess the effectiveness of the interventions on students' computer memory knowledge. The independent variables were: (a) the type of intervention, which included two levels (gaming application, non-gaming application), and (b) gender. The dependent variable consisted of scores on the posttest CMKT. Students' scores on the pretest CMKT served as a covariate in this analysis, to control for eventual pre-existing differences between the groups. Those differences were explored through one-way between-groups ANOVAs that compared pretest CMKT scores for: (a) the students of Group A and those of Group B, and (b) boys and girls.

Two-way between-groups ANOVAs were conducted in order to determine the impact of type of application used and gender on students' views on the application used, as measured by the feedback questionnaire. All the afore-mentioned analyses were performed using the SPSS statistical package. Level of significance was set at 0.05. Finally, the answers to the open-ended questions were grouped into categories according to their common themes.

3. Results

3.1. Comparison of the intervention groups as to biographical variables

The analysis of the students' biographical data showed that the random assignment of the classes of students to the two intervention groups (Group A and Group B) resulted in no statistically significant differences between the two groups. Specifically, the two groups did not differ significantly as to their proportion of boys and girls ($\chi^2 = 0.159$, df = 1, $p = 0.690$). Furthermore, the ANOVAs that compared the rest of the biographical variables for the students of Group A and those of Group B showed no statistically significant differences. Table 3 presents the relevant descriptive statistics.

3.2. Observation of the students' interaction with the applications

According to the informal data gathered from the researcher's observations, the students of Group A seemed enthusiastic when they were told that they would use a game for educational purpose. During their interaction with the game, they seemed very absorbed and interested in the task, and exhibited high levels of engagement in their effort to maintain their number of lives, reach the termination flags and achieve a high score. There was relative quiet during the intervention, broken by exclamations of satisfaction from students who had managed to get a flag, by exclamations of disappointment from students who had come across obstacles and by short dialogues regarding the exchange of procedural information and tips about the game. Those exclamations and dialogues were initiated mainly by boys, whereas girls seemed to play more on their own. The students of Group B also showed willingness and interest in using the educational website. However, although the two applications were similar, the students of Group B seemed less attentive and less engaged in interacting with the learning material and in answering the questions. The level of noise in the computer laboratory was higher than in the case of the game, and certain students (mainly boys) even initiated discussions that were totally irrelevant to the intervention. Finally, both the students of Group A and those of Group B seemed to find their way through their respective application easily.

3.3. Comparison of the applications as to their learning outcomes

The analysis of the CMKT pretest scores showed that: (a) there was no statistically significant difference in the performance in the pretest [$F(1,86) = 2.625$, $p = .109$] between the students of Group A ($M = 13.83$, SD = 3.33) and the students of Group B ($M = 14.93$, SD = 2.97), which indicates that the two groups had similar background knowledge on computer memory, (b) there was a statistically significant difference in the performance in the pretest [$F(1,86) = 6.602$, $p = .012$] in favour of boys ($M = 15.15$, SD = 3.25) over girls ($M = 13.45$, SD = 2.92), which denotes that boys had greater background knowledge on computer memory than girls.

Before conducting the ANCOVA on students' CMKT posttest scores to evaluate the effectiveness of the two interventions and the mediating influence of gender, preliminary checks were performed to confirm that there was no violation of the assumptions of normality, linearity, homogeneity of variances and homogeneity of regression slopes (Pallant, 2001). Descriptive statistics for the ANCOVA are presented on Table 4. After adjusting for CMKT scores in the pretest (covariate), the following results were obtained. A statistically significant main effect was found for type of intervention on the CMKT posttest scores [$F(1,83) = 8.853$, $p = .004$] in favour of Group A, which indicates that the students that had used the gaming application (Group A) performed significantly higher in the CMKT posttest than those that had used the non-gaming one (Group B). Hypothesis I was, thus, confirmed. The main effect for gender on the CMKT posttest scores was not found to be statistically significant [$F(1,83) = 2.519$, $p = .116$], which denotes that, overall, boys and girls exhibited similar achievement. Furthermore, there was no statistically significant interaction effect between the type of intervention and gender on the CMKT posttest scores [$F(1,83) = 0.148$, $p = .701$], which suggests that both within Group A and within Group B, boys' and girls' achievement did not differ significantly. Hypothesis III was, thus, not supported.

The significant initial gender difference in CMKT scores may be attributed to boys' traditionally greater contact and familiarity with computer technology. Indeed, the ANOVAs that explored gender differences as to the biographical variables of the study revealed that although boys did not differ significantly in frequency of computer use ($M = 3.26$, SD = 0.98) from girls [$M = 2.93$, SD = 1.00; $F(1,86) = 2.492$, $p = .118$], boys were significantly more frequent computer game players ($M = 3.00$, SD = 0.82) than girls [$M = 2.21$, SD = 0.78; $F(1,86) = 21.165$, $p < .001$], and reported significantly greater liking of games ($M = 3.76$, SD = 1.10) than girls [$M = 3.17$, SD = 1.15; $F(1,86) = 6.161$, $p = .015$]. Furthermore, boys reported significantly greater computer experience ($M = 3.61$, SD = 1.00) than girls [$M = 2.98$, SD = 0.92; $F(1,86) = 9.450$, $p = .003$], and significantly greater gaming experience ($M = 3.89$, SD = 1.02) than girls [$M = 2.79$, SD = 0.92; $F(1,86) = 28.308$, $p < .001$]. However, despite boys' greater involvement in, liking of and experience in computer games, from which one would expect a significant gender difference in favour of boys in the posttest scores within Group A, no such difference was noted.

3.4. Comparison of the applications as to their appeal to students

In order to explore the impact of type of intervention and gender on students' views on the application that they had used, four scores were calculated for each student: The means of the student's answers to the items corresponding to each of the four dimensions of the first part of the feedback questionnaire. Afterwards, for each dimension, the means of the scores were compared through 2×2 ANOVA. Table 5 presents the relevant descriptive statistics, whereas Table 6 presents the main effects for type of intervention and gender, and the interaction effect.

As deduced from Tables 5 and 6, significant main effects for type of application were detected on dimensions 'overall appeal' and 'educational value'. The students of Group A found the application that they had used significantly more appealing and educationally fruitful

Table 4
Descriptive statistics for pretest and posttest CMKT scores by intervention group and gender

Test	Gender	Group A		Group B	
		M	SD	M	SD
Pretest	Boys	14.88	3.29	15.50	3.25
	Girls	12.52	2.96	14.38	2.64
	Total	13.83	3.33	14.93	2.97
Posttest	Boys	22.50	3.94	19.75	3.99
	Girls	19.76	4.19	18.19	4.85
	Total	21.28	4.24	18.95	4.47
Adjusted means[a]	Boys	22.28	–	19.28	–
	Girls	20.50	–	18.17	–
	Total	21.39	–	18.73	–

[a] Adjusted means using pretest scores as a covariate.

Table 5
Descriptive statistics of students' responses by intervention group and gender

Dimension	Gender	Group A		Group B	
		M	SD	M	SD
Overall appeal	Boys	3.29	1.01	2.67	0.75
	Girls	3.41	0.60	2.81	0.79
	Total	3.35	0.85	2.74	0.76
Quality of user interface	Boys	3.81	0.67	3.78	0.53
	Girls	3.65	0.51	3.78	0.66
	Total	3.74	0.60	3.78	0.59
Accessibility of learning material and questions	Boys	3.73	0.68	3.48	0.85
	Girls	3.19	0.56	3.29	0.56
	Total	3.49	0.68	3.38	0.71
Educational value	Boys	3.78	0.84	3.14	0.63
	Girls	3.74	0.65	3.39	0.78
	Total	3.76	0.75	3.27	0.71

Table 6
Main effects and interaction effect of type of intervention and gender on students' responses

Dimension	Main effect for type of intervention		Main effect for gender		Interaction effect	
	F(1,84)	*p*	*F*(1,84)	*p*	*F*(1,84)	*p*
Overall appeal	12.440	.001	0.558	.457	0.005	.943
Quality of user interface	0.158	.692	0.396	.531	0.343	.559
Accessibility of learning material and questions	0.311	.578	6.426	.013	1.487	.226
Educational value	9.759	.002	0.462	.499	0.879	.351

than did the students of Group B find their respective application. The former, thus, manifested more positive views on and stronger preference towards the application that they had experienced compared to the latter. Hypothesis II was, thus, confirmed. No other significant main effects for type of application were found, which can be explained by the fact that the two applications were designed to be equally usable, and comprised identical content.

A significant main effect for gender was found only on dimension 'accessibility of learning material and questions'. Overall, girls found the subject matter and questions contained in the applications less easy to cope with than boys did. This may be attributed to girls' lesser initial knowledge on computer memory. However, no statistically significant interaction effects were found. The afore-mentioned girls' greater difficulty, thus, did not depend on the type of application. Furthermore, both within Group A and Group B, no significant gender differences were noted as to students' views on the overall appeal, quality of user interface and educational value of the application used. Hypothesis IV was, hence, not supported.

The analysis of the second part of the feedback questionnaire revealed that the students of both groups were positive towards the adoption of the learning modes that they had experienced at school, with the students of Group A finding their respective learning mode more engaging, effective, active and 'relaxed' than those of Group B. As stated by a girl from Group A: '*It's more enjoyable and active. You never get bored as in traditional teaching because you concentrate on a goal. This helps you retain elements in your memory easily and understand concepts that are difficult in order to advance in the game*'. Regarding students' suggestions for the improvement of the applications that they had used, the students of Group A were more willing to suggest improvements, and also more demanding than those of Group B. The proposals made by the former referred mainly to the improvement of the game graphics (e.g. the adoption of 3D graphics), and also to the addition of sounds and music, and to the addition of a greater variety of activities and a more adventurous plot (e.g. more objects to collect, more rooms, more rivals and competition). Finally, although for both groups the experience of participating in the experiment was novel within the scholastic environment and was valued as interesting and educationally beneficial, the students of Group A were certainly more enthusiastic about it than those of Group B. As stated by a boy from Group A: '*Original and impressive experience. I was really amused and I learned a lot about computer memory. I'd like to have the game in my computer at home as well*'.

4. Discussion and conclusions

This study evaluated the learning effectiveness and motivational appeal of a computer game targeted at the learning of computer memory concepts taught within the Greek high school CS curriculum, as compared to a similar non-gaming application in the form of a website. Furthermore, the study investigated potential gender differences in the game's learning effectiveness and motivational appeal. In what follows, the main findings and their implications are discussed.

The study demonstrated that the DGBL approach was both more effective in promoting students' knowledge of computer memory concepts and more motivational for students than the non-gaming approach. It can, thus, be concluded that educational computer games can be exploited as learning environments within high school CS courses, given that, as deduced from this study, they can considerably improve both knowledge of the embedded subject matter and student enjoyment, engagement and interest in the learning process. Those findings seem to support the outcomes of certain prior studies (Klawe, 1999; Rosas et al., 2003) and those of a very recent study (Ke & Grabowski, 2007) on school children, which showed that educational computer games contributed to increased academic achievement and motivation compared to traditional teaching in areas such as mathematics and science. However, the findings of the present study are perhaps a stronger indicator in favour of DGBL, given that in this study: (a) DGBL was not compared to traditional teaching, which students find boring (Prensky, 2003), but to another appealing form of ICT-based learning, and (b) the participants were not children, but adolescents who are more difficult to engage in school learning and harder to motivate than children (e.g. Eccles & Midgley, 1989). In addition, they suggest that DGBL can be effective in a variety of subjects – other than computer programming in which games have so far been exploited within scholastic CS education – which are included in scholastic CS curricula, and which require factual knowledge and conceptual understanding, such as the topic of computer memory.

Regarding gender issues, as shown in the study, despite the fact that the boys of the sample exhibited significantly greater involvement with, liking of and experience in computer gaming outside school as well as significantly greater initial knowledge of the embedded subject matter, and greater interaction among them during the intervention, the learning gains that boys and girls achieved through the use of the game did not differ significantly. Furthermore, no significant gender differences were found in students' views on the overall appeal, quality of user interface, and educational value of the game used. It can, thus, be concluded that, within high school CS education, DGBL can be equally effective and motivational for boys and girls. Those findings contrast the findings of certain previous studies into school children which showed that computer games were more effective with boys than with girls (De Jean et al., 1999; Young & Upitis, 1999) and meet the outcomes of a recent study into school children (Ke & Grabowski, 2007), which found that gender did not influence the learning effectiveness and motivational appeal of games.

The specific game employed in this study was relatively simple and designed to be used within short-term interventions in schools. It certainly lacks the sophisticated graphic designs, sound effects and storylines of the immersive multiplayer games and other commercial games that students play outside school. However, this perhaps reinforces the importance of the findings. Given that a rather simple game had positive effects on knowledge acquisition and student motivation, it can be expected that a more sophisticated game would yield even more positive results. Nevertheless, in the latter case, the complexity and attractiveness of the environment may perhaps constitute a distraction from the objectives of learning and the learning process. This poses an interesting question for future research and is further discussed later.

It should also be noted that, as deduced from the results, although the students that had used the game were enthusiastic about using such an application for learning purposes within school, the improvements that they suggested to the game revealed that they are particularly demanding mainly regarding game multimedia and plot, which denotes that students expect to find in the educational games that they use within school the elements that they encounter in the games that they play outside school. This finding meets the outcomes of certain other studies (Duplantis et al., 2002; Facer et al., 2004; Virvou et al., 2005), in which the participating students would have preferred a more sophisticated gaming environment. An educational computer game should, thus, bear the features of the multimedia-rich, adventurous games that students experience outside school in order to meet students' expectations, to retain their interest and to be exploitable within long-term educational interventions.

The present study had certain limitations. The study involved a short-term intervention in schools, and also investigated short-term retention of computer memory knowledge. A long-term intervention with a follow-up test would have provided more insight into the effects of DGBL on student CS achievement and motivation, and would have further supported the conclusions of the study. However, as commented earlier in this paper, such an investigation was impossible to conduct due to restrictions in the timetables of the high schools.

Finally, this study opens up interesting perspectives for future research. Firstly, it would be interesting to investigate the long-term learning effects and motivational impact of a game, when the latter is used regularly within the scholastic CS curriculum and, thus, becomes less of a novelty for students. Secondly, as mentioned earlier, an interesting research question is that of an optimal balance between, on the one hand, the level of sophistication and complexity of a game (in terms of multimedia design and storyline) and, on the other hand, its learning effectiveness and motivational appeal. This issue could be investigated through the comparative evaluation of different configurations of an educational game (e.g. of low, medium and high complexity), all targeting the same learning objectives and subject matter, within scholastic CS courses. In such a research design, the impact of individual student characteristics (e.g. gender) could also be studied.

This study demonstrated that DGBL can promote curricular knowledge and student motivation in core academic subjects of high school CS. This finding has implications for both designers of educational software and CS educators. The former should produce educational games, aligned with the needs of real scholastic CS curricula, free of gender bias, and competitive with the commercial games that students play outside school, ideally in collaboration with experienced game designers and CS educators. The latter should not underestimate the educational value of games, and should be given the opportunity to receive appropriate training not only on the didactical exploitation of educational games within CS courses, but also on their design and development. This would enable them, on the one hand, to produce small games for their own students, and, on the other hand, to contribute to multi-disciplinary teams engaged in the construction of larger scale games for CS education.

References

Cassell, J., & Jenkins, H. (Eds.). (1998). *From barbie to mortal kombat: Gender and computer games*. Cambridge, MA: MIT Press.

De Jean, J., Upitis, R., Koch, C., & Young, J. (1999). The story of 'Phoenix Quest': How girls respond to a prototype language and mathematics computer game. *Gender and Education, 11*(2), 207–223.

Dempsey, J., Lucassen, B., & Rasmussen, K. (1996). The instructional gaming literature: Implications and 99 sources. University of South Alabama, College of Education, Technical Report No. 96–1.

Downes, T. (1999). Playing with computing technologies in the home. *Education and Information Technologies, 4*(1), 65–79.

Duplantis, W., MacGregor, E., Klawe, M., & Ng, M. (2002). 'Virtual family': An approach to introducing java programming. *ACM SIGCSE Bulletin, 34*(2), 40–43.

Eccles, J., & Midgley, C. (1989). Stage-environment fit: Developmentally appropriate classrooms for young adolescents. In C. Ames & R. Ames (Eds.). *Research on motivation in education* (Vol. 3, pp. 139–186). New York: Academic Press.

Facer, K. (2003). Computer games and learning. http://www.futurelab.org.uk/resources/documents/discussion_papers/Computer_Games_and_Learning_discpaper.pdf [last access: 27/08/2007].

Facer, K., Joiner, R., Stanton, D., Reid, J., Hull, R., & Kirk, D. (2004). Savannah: Mobile gaming and learning? *Journal of Computer Assisted Learning, 20*(6), 399–409.

Giakoumakis, E., Gyrtis, K., Belesiotis, B., Xynos, P., & Stergiopoulou-Kalantzi, N. (2002). Computer science and computer applications. Athens: Ministry of Education.

Hagborg, W. (1992). Grades and motivational orientation among high-school students. *Journal of Psychoeducational Assessment, 10*(4), 355–361.

Harris, S. (1999). Secondary school students' use of computers at home. *British Journal of Educational Technology, 30*(4), 331–339.

Kafai, Y. (2001). The educational potential of electronic games: From games-to-teach to games-to-learn. http://culturalpolicy.uchicago.edu/conf2001/papers/kafai.html [last access: 27/08/2007].

Ke, F., & Grabowski, B. (2007). Game playing for maths learning: Cooperative or not? *British Journal of Educational Technology, 38*(2), 249–259.

Kirriemuir, J. (2002). Video gaming, education and digital learning technologies. *D-Lib Magazine, 8*(2).

Kirriemuir, J., & McFarlane, A. (2004). Literature review in games and learning: A Report for NESTA Futurelab. http://www.futurelab.org.uk/resources/documents/lit_reviews/Games_Review.pdf [last access: 27/08/2007].

Klawe, M. (1999). Computer games, education and interfaces: The E-GEMS project. In *Proceedings of the graphics interface conference* (pp. 36–39).

Malone, T. (1980). What makes things fun to learn? Heuristics for designing instructional computer games. In Proceedings of the 3rd ACM SIGSMALL Symposium and the 1st SIGPC Symposium (pp. 162–169). Palo Alto, USA.

McFarlane, A., Sparrowhawk, A., & Heald, Y. (2002). Report on the educational use of games. http://www.teem.org.uk/publications/teem_gamesined_full.pdf [last access: 27/08/2007).

Mumtaz, S. (2001). Children's enjoyment and perception of computer use in the home and the school. *Computers and Education, 36*(4), 347–362.

Natvig, L., & Line, S. (2004). Age of computers: Game-based teaching of computer fundamentals. *ACM SIGCSE Bulletin, 36*(3), 107–111.

Oblinger, D. (2004). The next generation of educational engagement. *Journal of Interactive Media in Education, 2004*(8), 1–18.

Overmars, M. (2004). Creating maze games. http://www.gamemaker.nl/ [last access: 03/10/2005].

Pallant, J. (2001). *SPSS survival manual*. Buckingham, UK: Open University Press.

Papakonstantinou, G., Tsanakas, P., Kozyris, N., Manousopoulou, A., & Matzakos, P. (1999). *Computer systems technology and operating systems*. Athens: Ministry of Education.

Papastergiou, M. (2008). Are Computer Science and Information Technology still masculine fields? High school students' perceptions and career choices. *Computers and Education, 51*(2), 594–608.

Papastergiou, M., & Solomonidou, C. (2005). Gender and information and communications technology: Greek high school students' favourite internet activities. *Computers and Education, 44*(4), 377–393.

Prayaga, L. (2005). Game technology as a tool to actively engage K-12 students in the act of learning. In *Proceedings of the 6th ACM conference on information technology education* (pp. 307–310). Newark, NJ, USA.

Prensky, M. (2001). *Digital game-based learning*. New York: McGraw-Hill.

Prensky, M. (2003). Digital game-based learning. *ACM Computers in Entertainment, 1*(1), 1–4.

Randel, J., Morris, B., Wetzel, C., & Whitehill, B. (1992). The effectiveness of games for educational purposes: A review of recent research. *Simulation and Gaming, 23*(3), 261–276.

Rosas, R., Nussbaum, M., Cumsille, P., Marianov, V., Correa, M., Flores, P., et al. (2003). Beyond nintendo: Design and assessment of educational video games for first and second grade students. *Computers and Education, 40*(1), 71–94.
Virvou, M., Katsionis, G., & Manos, K. (2005). Combining software games with education: Evaluation of its educational effectiveness. *Educational Technology and Society, 8*(2), 54–65.
Werner, L., Campe, S., & Denner, J., (2005). Middle school girls + games programming = information technology fluency. In *Proceedings of the 6th ACM conference on information technology education* (pp. 301–305). Newark, NJ, USA.
Young, J., & Upitis, R. (1999). The microworld of Phoenix Quest: Social and cognitive considerations. *Education and Information Technologies, 4*(4), 391–408.
Yu, F., Chang, L., Liu, Y., & Chan, T. (2002). Learning preferences towards computerised competitive modes. *Journal of Computer Assisted Learning, 18*(3), 341–350.

Marina Papastergiou graduated in Computer Engineering and Informatics from the University of Patras (Greece) and received a Master's and a Ph.D. diploma in Informatics Education from the University of Paris VII (France) and the University of Thessaly (Greece), respectively. She is a lecturer at the University of Thessaly and her research interests focus on Informatics in Education.