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40 Abstract

This study addresses the learning of Information and Communication Technologies (ICT) concepts by physical education and sport science students through a computer game. Its aims are: (a) the design of the prototype of a computer game aimed at supporting the development of an appropriate mental model about how a computer works by the students, and (b) the evaluation of the impact of the use of this prototype on students as to appeal, basic usability issues and learning outcomes. The most significant elements of the game prototype (narrative, characters, interface, scenarios, puzzles, gameplay) are presented in connection with the constructivist learning principles that guided the game design. A hundred and three (103) physical education and sport science students participated in the evaluation of the game prototype, which was conducted through pretest and posttest written questionnaires that elicited both quantitative and qualitative data. The data analysis showed that the game prototype was well-accepted as an alternative learning tool for ICT, compared to traditional learning tools, and that most game elements elicited average to positive responses from the students. It was also found that the game prototype had a significant positive effect on students' knowledge regarding the concepts of input, program, output and their interplay, and that it helped certain students overcome their misconceptions and form more scientifically acceptable and elaborate mental conceptions about basic functions of a computer. Future improvements and extensions to the game as well as future research perspectives are discussed on the basis of the findings.

41 Keywords separated by ' - ': Computer game - Digital game-based learning - ICT - Physical education - Sport science - Constructivism

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Design and evaluation of a computer game for the learning of Information and Communication Technologies (ICT) concepts by physical education and sport science students

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Abstract This study addresses the learning of Information and Communication Technologies (ICT) concepts by physical education and sport science students through a computer game. Its aims are: (a) the design of the prototype of a computer game aimed at supporting the development of an appropriate mental model about how a computer works by the students, and (b) the evaluation of the impact of the use of this prototype on students as to appeal, basic usability issues and learning outcomes. The most significant elements of the game prototype (narrative, characters, interface, scenarios, puzzles, gameplay) are presented in connection with the constructivist learning principles that guided the game design. A hundred and three (103) physical education and sport science students participated in the evaluation of the game prototype, which was conducted through pretest and posttest written questionnaires that elicited both quantitative and qualitative data. The data analysis showed that the game prototype was well-accepted as an alternative learning tool for ICT, compared to traditional learning tools, and that most game elements elicited average to positive responses from the students. It was also found that the game prototype had a significant positive effect on students' knowledge regarding the concepts of input, program, output and their interplay, and that it helped certain

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students overcome their misconceptions and form more scientifically acceptable and elaborate mental conceptions about basic functions of a computer. Future improvements and extensions to the game as well as future research perspectives are discussed on the basis of the findings.

Keywords Computer game · Digital game-based learning · ICT · Physical education · Sport science · Constructivism

1 Introduction

Digital Game Based Learning (DGBL) is a learning approach that promotes the integration of educational content and learning objectives within the context of computer and video game-based activities (Prensky 2001a). DGBL can be used for the learning of almost all subjects (Coffey 2009). In fact, previous research has shown that computer games have been effective in increasing motivation and achievement of both children and adults in various areas, such as science and mathematics (Smith and Muhro 2009), language (McGraw et al. 2009; Liu and Chu 2010), geography (Virvou et al. 2005) and computer science (Papastergiou 2009a; Kordaki 2011).

Among the acclaimed benefits of DGBL is that computer games can make learning more efficient, engaging, interesting and enjoyable (Malone 1980) and that they can incorporate sound principles and models of learning (Eck 2006). Another reason why DGBL is being widely studied today is that traditional educational methods may no longer be effective for the current generation of learners (Srinivasan et al. 2008), whose way of thinking, learning and processing information has been changed thanks to technology (Prensky 2001b). In fact, the research conducted thus far has been able to support some of the acclaimed benefits of DGBL with encouraging results concerning student engagement and learning (Tüzün 2007; Srinivasan et al. 2008).

The research described in this paper began as an effort to enhance the motivation and learning of physical education and sport science students regarding concepts related to Information and Communication Technologies (ICT). Specifically, in the Department of Physical Education and Sport Science (DPESS) of the University of X (*institution name removed for blind review*), 'Computers' is a compulsory ICT course taught to all first-year undergraduate students, during their first semester of academic studies. Its theoretical curriculum comprises topics such as: a model of how a computer works, computer typology, hardware of a personal computer, software types, computer networks and the Internet. The instructor of the course is one of the authors (M.P.). In line with her previous experiences of teaching ICT concepts in a lecture format, students soon get bored and looked forward to actually using computers and the Internet. It was, thus, decided to experiment with introducing a game into the course, designed according to constructivist learning principles, which would embed topics of the theoretical curriculum of the course, and which could serve both as a motivation tool and a learning medium.

Although various games designed for the learning of computer science or ICT concepts at higher education level have already been reported in the research literature (e.g. Connolly et al. 2006; Hingston et al. 2006; Milone et al. 2009; Sindre et al. 2009), those games are mostly addressed at students of computer science or other ICT-oriented disciplines. To the best of the authors' knowledge, no research thus far has addressed the utilization of DGBL for the learning of ICT concepts by physical education and sport science students. Consequently, there is an absence of computer games specifically designed to support the learning of such concepts by physical education and sport science students. Nevertheless, today, it is widely acknowledged that those students should be helped to understand ICT concepts and to acquire ICT skills, given that ICT are increasingly becoming an integral part of the physical education curriculum and its instruction as well as of the everyday work of physical education teachers, athletic coaches and sport managers (Kocak 2003; Liang et al. 2006).

The aim of the study presented in this paper is twofold: (a) the design of the prototype of a computer game aimed at supporting the development of an appropriate mental model about how a computer works by physical education and sport science students, and (b) the evaluation of the impact of the use of this prototype on students as to its appeal, basic usability issues and learning outcomes.

This paper makes an original contribution both to the area of DGBL and to the area of information literacy training given that it provides a concrete case study on the design of a game prototype for the learning of ICT concepts by students who study a non ICT-oriented discipline, namely physical education and sport science, and on the evaluation of this prototype in real academic settings.

This paper is organized as follows: in the next section, the conceptual framework of the design of the proposed computer game is reported. Next, the design and basic features of a prototype of this game are presented. Subsequently, an evaluation study of the prototype -on real students- addressing motivational, usability and learning aspects is presented. Finally, the results of this study are discussed and conclusions are drawn.

2 Conceptual framework

In what follows, the influential role of digital games in contemporary society and in young people's lives is first documented. Then, the main principles of constructivist approaches to learning, which have inspired the design of the game prototype, are discussed and their interplay with DGBL environments is analyzed.

2.1 Digital games, young people and learning

Digital gaming entertainment is one of the most profitable industries so far. This can be proven by the statistics released annually by the Entertainment Software Association, according to which, computer or video games are played in the majority of American households and game sales accumulate billions of dollars each year (ESA 2009). Furthermore, the applications defined as 'serious games', namely games designed for specific purposes besides mere entertainment (Abt 1987), are being used in sectors as varied as health promotion, military training, advertising, production, science, research, and education (Sawyer and Smith 2008).

Many scholars have argued that appropriately designed computer games provide a compelling context for learning (e.g. Kafai 2001; Tennyson and Jorczak 2008). In the course of playing such games, young people can be introduced to new concepts, topics and skills -during both formal (i.e. classroom) and informal (i.e. outside class) education- which they can continue to explore through offline reading, discussions or activities (Fisch 2005). And given that the outcomes of informal learning are argued to be superior to those of formal learning (Conner 1997; Cross 2006), this constitutes a reason to explore the introduction of games in educational environments. It is also worth noting that computer games play a central role in young people's lives and constitute a very popular computer activity for them (Kirriemuir and McFarlane 2004; Gros 2007). Research into games and play has also demonstrated that players can attain a state of 'flow' (Csikszentmihalyi 1990) summarized as "the state in which we are so involved in something that nothing else matters". In fact, the uniqueness of the DGBL approach comes with the involvement and the excitement of the accomplishment (Rajaravivarma 2005). Based on Csikszentmihalyi's flow theory and on experiential learning theory, Kiili (2005a) presents an experiential gaming model, which can guide the design and evaluation of engaging and motivational educational computer games. According to the model, the environment of such a game should offer a player appropriate learning experiences, immediate feedback, clear goals and challenges that match his/her skill level, with a view to maximizing flow, which, in turn, can have a positive impact on the learning effectiveness of the game (Kiili 2005a). Among other factors that can facilitate flow within such a game are: an engaging gameplay, a captivating storyline and good usability (Kiili 2000a; Kiili 2005b).

It is also widely believed that DGBL environments favor the acquisition of essential learning competencies, such as logical and critical thinking, reasoning ability as well as problem-solving skills (McFarlane et al. 2002; Gros 2007; Chuang et al. 2010). Most importantly, they can support learning in ways different from those often in evidence, or explicitly valued, in academic settings (Kirriemuir and McFarlane 2004). In fact, young people seem to expect different approaches to learning, shaped by their frequent interaction with computer games and information technology tools outside academic settings (Prensky 2001a, b).

2.2 Constructivist learning theories and digital games

The adoption of principles of learning theories in the design of computer games is of great importance, especially in games dedicated to educational purposes. Among the three main paradigms of learning theories (namely behaviorism, cognitivism and constructivism), constructivism seems to be the most relevant to DGBL (Oblinger 2004). Constructivist views of learning are also adopted in Kiili's (2005a) aforementioned experiential gaming model. In fact, constructivist learning theories acknowledge the *active*, *subjective* and *constructive* nature of learning (Jonassen 1999). According to these theories, the role of *motivational activities* is also crucial, so that learners are encouraged to actively and passionately engage in the construction of their knowledge (Jonassen 1999; Land and Hannafin 2000). Specifically, motivational or affective factors, such as intrinsic motivation and personal goals, along with the motivational characteristics of learning tasks, play a significant role in the learning process (Ford 1992; Alexander and Murphy 1998). Social constructivist theories of learning also acknowledge the role of tools (Vygotsky 1974), and especially the role of *computer tools* (Noss and Hoyles 1996), in supporting students to enhance their Zone of Proximal Development (i.e. the difference between what a learner can do without help and what he/she can do with help) by exploring the knowledge that is integrated within such tools. The provision of appropriate *scaffolding* (i.e. support) on learners' actions within a learning environment is also of great importance in assisting students' learning (Vygotsky 1974). In the context of social learning perspectives, the role of *situation*, and that of the general *social context* where learning takes place, shapes the learners' activity and provides them with opportunities to *construct meaning* (Lave and Wenger 1990; Bandura 1997). In fact, Situated Learning Theory posits that learning is unintentional and situated within authentic activity, context, and culture (Lave 1988; Lave and Wenger 1990).

Given that within a constructivist learning environment learners can not only construct knowledge, but also put into practice what they have learned in different situations, interact in order to advance, analyze data and test hypotheses (Jonassen et al. 1995), a digital game is a challenging medium for the creation of constructivist learning environments. In fact, digital games not only provide a source of strong motivation for student *engagement* in learning, but they can support *active* and *experiential* learning, and they can favor *activation of prior knowledge*, given that players must use previously learned information in order to advance in the game (Oblinger 2004). Games also provide *immediate feedback* enabling players to test hypotheses and learn from their actions, they encompass opportunities for *self-assessment* through the mechanisms of scoring and reaching different levels, and they can offer opportunities for social interactions (Oblinger 2004). Constructivist learning principles are sometimes encountered even in commercial digital games that were not specifically created for educational purposes (Muñoz-Rosario and Widmeyer 2009).

Gee (2003) introduced a set of guidelines to be followed during the design process of a game that truly reflects the constructivist approach. From this set, the following guidelines (in a form of appropriate principles) were selected by Bonk and Dennen (2005) and revised by Muñoz-Rosario and Widmeyer (2009): (P1) *probing principle*: the learner should be encouraged to fund his/her own hypotheses and test them in action, (P2) *distributed principle*: learners should be able to interact and share knowledge with others, (P3) *multiple routes principle*: learners should be given access to different progression routes and choices, (P4) *practice principle:* learners should be able to practice as much as they want, (P5) *psychosocial moratorium principle*: unlike real-life environments, learners should be able to take risks, (P6) *regime of competence principle*: learners should be challenged to go beyond their comfort zone, (P7) *engaging principle*: the game should be attractive enough for the learners to engage in it, with elements such as theme and plot story, (P8) *user interface ease of use principle*: the interface should be intuitive, consistent and easy to navigate, (P9) *achievement principle*: learners should be rewarded for their progress in the game, as a form of encouragement. The achievement could be anything (e.g. unlocking abilities upon advancing to a new level, receiving a reward upon completing a mission).

These principles are meant to be applied in large scale gaming environments shared by various simultaneous players. However, some of them can also be applied in the creation of smaller scale, single-player games. For the design of the game prototype presented in this paper an attempt was made to incorporate most of the design principles mentioned above (except P2 and P5, the *'distributed principle'*—which refers to multi-player games—and the *'psychosocial moratorium principle'*) as well as main aspects deriving from the social and constructivist theoretical framework presented in this section, namely: active and experiential learning, learners' engagement, motivational activities, activation of prior knowledge, self-assessment, scaffolding, and appropriate social context for construction of meaning.

3 Design and basic features of the prototype

The prototype here presented is the introductory part of a game that is intended to be integrated into the 'Computers' course and to be used as a supplementary learning tool exclusively for the students of the course. The game is envisaged to include several levels, each of which will be divided into acts consisting of puzzles that the student has to gradually solve. A draft preliminary version of part of the prototype is briefly presented in Authors (2011).

The prototype consists of two acts and aims to help students form an appropriate, functional mental model of the computer without—at this introductory stage—examining the computer's inner workings. Specifically, the purpose of the two acts is to help students conceptualize the computer according to the model of the programmable data processor, and their instructional design was inspired by the presentation of the model in Forouzan (2003). The students are expected to understand the basic functions that the computer performs according to that model, namely that it receives input data, processes those data guided by the program, and produces output data, and to conceive the interplay between input, program and output.

The game's target group is first-year physical education and sport science undergraduate students. Besides attending classes, those students also engage in sports. According to the constructivist learning principles that were presented earlier in this paper, learning should be motivational, challenging and personally relevant. It was, thus, decided to embed the theme of sports into the game design with a view to providing a meaningful context with which the specific target group could relate (implementation of P7, the afore-mentioned *'engaging principle'*).

In this section, the most significant elements of the prototype design are presented in connection with the constructivist learning principles that guided the design. The narrative, characters, interface, scenarios and challenges (puzzles) are presented first, followed by a description of the game mechanics and gameplay, and by a walkthrough of the two acts (Act 1 and Act 2). The section ends with a brief report on the implementation of the prototype.

3.1 Narrative

An engaging narrative was sought with a view to rendering the game appealing and challenging for students and to further incorporating P7 (the *'engaging principle'*) into the game design. Narrative plays an important part in educational games: it can motivate the player (Waraich 2004), it can create a supportive context for the necessary interpretation and order inside the game (Nitsche 2008), and may help the player make sense of the information and challenges he/she encounters. It can, thus, favor situated learning, which, as already mentioned, constitutes a basic tenet of constructivist learning. In the game, the player follows a storyline structured in successive acts, which is hoped to help him/her make sense of what he/she encounters within the game environment and to invoke enough curiosity to move to the next act.

The storytelling is linked to the Olympic Games of Athens, in a future where some technological progress has been made, but older hardware and software is still being used. The player assumes a character codenamed 'Hero'. Hero is a physical education and sport science student working as a volunteer for the Games, and is accompanied by a hovering robot (henceforth called 'Robot'). The computing and networking infrastructures of the Olympic Games facilities are suddenly affected by a series of crashes and, inevitably, Hero and Robot are involved in this chaos and have to solve the enigma behind the computer and network instability. The game environment encourages active, problem-based and experiential learning, which is a basic feature of constructivist learning environments. A description of past events is embedded in the storytelling with a view to making the plot setting more believable and to explaining the presence of outdated, but still functional equipment, mixed with more technologically sophisticated equipment in the game scenarios. With such a story development it is possible to justify the presence of old computers, since it is necessary to introduce elements in a futuristic setting, which however can be related to the current computer technology the DPESS student has to learn about.

3.2 Characters

The main character (Hero) is a realistic character with which the players can identify (given that he is a physical education and sport science student). This can render the game environment more personally relevant for them and their 'immersion' into it easier (application of P7, the *'engaging principle'*). The protagonist has a helper in his explorations, Robot. Its purpose is to help Hero in various situations, by providing contextual information as well as useful hints during the puzzle-solving process. Therefore, Robot is familiar with several basic ICT concepts, although this knowledge is incomplete. Robot is intended to provide scaffolding to the student's actions, an element that is considered to help learning, according to the constructivist learning principles. Alexis is another character with whom Hero and Robot frequently interact. Alexis is the protagonist's 'geeky' friend, who serves as a volunteer (system administrator's auxiliary) in the Olympic Games ITC (Information Technology Center). Alexis is one of the main sources of ICT-related information within the game. His dialogues with Hero and Robot can provide the player with useful hints, which may help him/her solve puzzles or consolidate the knowledge acquired through the puzzle-solving process. In this way, a tier of additional scaffolding is provided to the player. Furthermore, the fact that the player can interact with Robot and Alexis introduces a sense of social interaction into the game (although the game is not actually multiplayer). 'Staff member' is another secondary character, who works officially for the Games and who is stressed about the commotion caused by the system crashes. This character was introduced to assign Hero various tasks to perform, including puzzles to solve. On the whole, Hero is provided with various opportunities to form his own hypotheses and test them in action during the game play (implementation of P1 and P4, the afore-mentioned *'probing'* and *'practice'* principles).

3.3 Interface

The protagonist possess a Portable Computing Device (henceforth called 'the PCD'), which plays a vital role in the game given that it can be used by the player during the puzzle-solving process, and it also stores a 'Knowledge Database' of the ICT-related information discovered thus far by the player (initially this database is empty). The player can run various applications on the PCD (initially there are no applications to run). However, as he/she advances in the game, solved puzzles unlock new applications on the PCD as well as new content in the 'Knowledge Database' (implementation of P9, the *'achievement principle'*). In accordance with the constructivist learning approach, the player has to construct knowledge through the puzzle-solving activities and through his/her interactions with the characters of the game. Then, the database entries that are relevant to the concepts that underlie the puzzles get unlocked so that the player can conceptualize and consolidate the recently acquired knowledge. By plugging 'memory chips' into the PCD, the player can access additional applications and content. 'Memory chips' are the most commonly encountered objects within the game and their contents depend on the specific act and puzzle. There is also an 'Inventory', where objects (e.g. 'memory chips') are placed for the protagonist to view and use, and a 'Hint system' intended to host Robot's hints). A simple interface, in the form of a slide menu was designed to allow the player to interact with these elements. Dialog boxes appear during cut scenes. They display the character with whom the protagonist is talking along with text. On the whole, care has been taken in the game's interface so that it be intuitive, consistent with the game narrative and easy to navigate (implementation of P8, the *'user interface ease of use principle'*).

3.4 Scenarios

Scenarios had to be in tune with the game's narrative and to include elements eye-catching enough for the player to click on and explore. The player can explore these elements in any order and engage in the puzzles embedded in the scenarios when he/she wishes (implementation of P3, the afore-mentioned *'multiple routes principle'*). The scenarios were drawn at a special angle as if they were seen through the protagonist's eyes.

3.5 Challenges

The game comprises a series of puzzles, which were merged into the storyline carefully and which require the player to get actively involved in the construction of new knowledge or in the application of already acquired knowledge. According to the constructivist approach to learning, these puzzles encourage exploratory learning as well as putting existent knowledge into practice in order to cope with real situations. Furthermore, they challenge the player to go beyond his/her comfort zone (implementation of P6, the *'regime of competence principle'*). The puzzles implemented thus far are presented in subsections 3.7 and 3.8.

3.6 Game mechanics and gameplay

Several elements from known game genres were incorporated into the game design. For instance, dialogues function as in most basic role-playing games, and scenes are explored by poking objects as in mystery solving adventures. In fact, the game is mainly an adventure game and this choice was made because adventure games are considered to be viable educational tools that can stimulate students' curiosity and can affect both their cognitive functions and motivation (Amory 2001). The basic game mechanics are as follows. After a brief introduction to a new act (which situates the act within the general game narrative), the player can: start exploring the scenario, interact with elements in the background, check the current objects in the 'Inventory', consult the 'Knowledge Database' on the PCD, and unlock applications on the PCD. At a point where he/she has advanced enough in his/her investigation, he/she can unlock a puzzle. Successfully solving the act's puzzle(s) will trigger the act's conclusion and the player will proceed to the next act (application of P9, the *'achievement principle'*).

3.7 Walkthrough of Act 1

Act 1 is situated in a basketball court, where Greece is playing against Spain and Hero serves as a volunteer. Suddenly the scoreboard displays strange characters. Hero and Robot go to the court's 'hardware backroom' (which is this act's scenario) to see what is happening (Fig. 1). All the systems have crashed and that is why the current scores have been erased. The player can explore the 'hardware backroom' by clicking on its various objects (e.g. on a PC), and getting relevant information (Fig. 2).

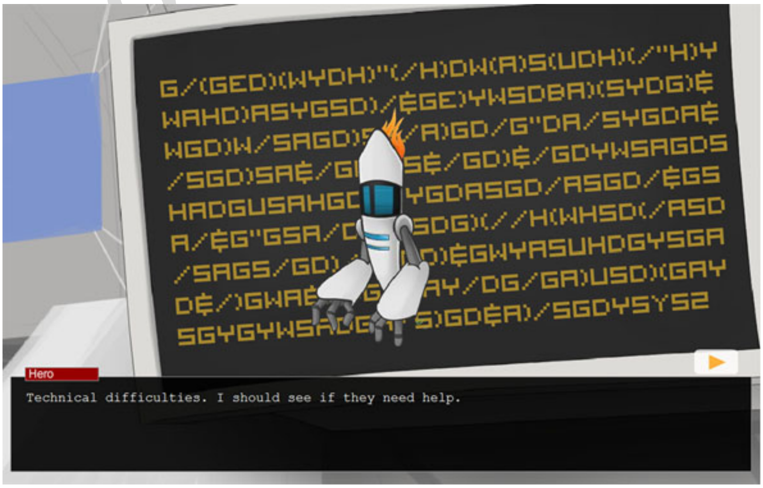

Fig. 1 Hero and Robot volunteer to help

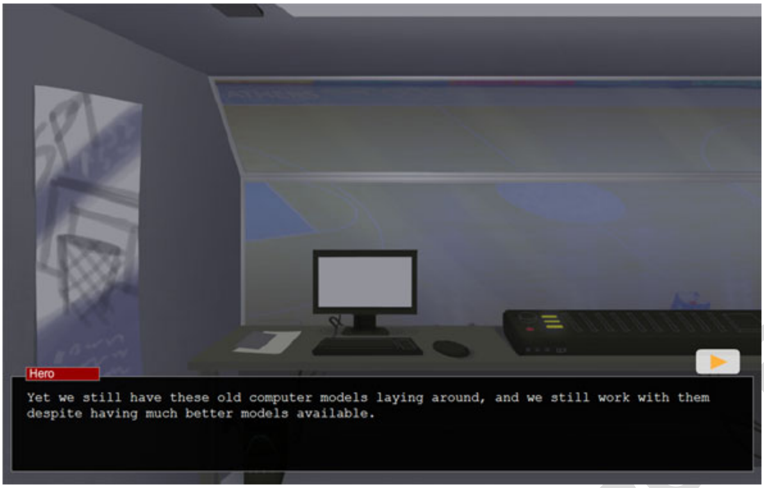

Fig. 2 Exploring the 'hardware backroom'

Suddenly, 'Staff member gives Hero a memory chip and a piece of paper, shouting "We need those scores right now!". The paper contains the points achieved thus far by the competing teams, and the only way to see the chip contents (and to unlock the act's puzzles) is to plug it into the PCD. When the player does so, the scattered and stacked pieces of a block diagram appear on the PCD screen, and the player has to put them together, otherwise he/she cannot advance (Fig. 3). The diagram depicts the model of the computer as a programmable data processor (Forouzan 2003), but the player is not given this information. Instead, through the process of trying to assemble the pieces, he/she can think hard on what the pieces represent, and on how they can be put together to make sense. When a piece is correctly placed, its outline changes color and a sound is heard. Thus, the player gets immediate feedback regarding the correctness (or not) of his/her hypotheses (application of P1, the *'probing principle'*). Only when he/she has successfully

Fig. 3 The first puzzle to solve on the PCD

assembled the diagram, does Robot provide an explanation of the model, which includes the concepts of input data, program and output data. Then, a new application is unlocked and runs on the PCD.

Robot informs Hero that he has to enter the points achieved by Greece and then by Spain in order to compute the current score for each team (the application makes the PCD perform an addition of the numerical data entered) (Fig. 4). The player has to execute the same program twice with different input data each time (different output is obtained), and, thus, has the opportunity to consolidate the previously introduced concepts of input, program and output through a concrete, 'hands-on' example. When done with this task, 'Staff member' asks the player the two scores. The plot advances to Act 2 only if he receives correct answers (and the erased scores are restored). It should be noted that when the player has successfully solved Act 1 puzzles, an entry on the concept of the program is unlocked in the 'Knowledge Database'.

3.8 Walkthrough of Act 2

After the basketball game, Hero and Robot go to the main room of the Information Technology Center (ITC) of the Olympic Stadium (which is this act's scenario) in order to visit Alexis and learn about the system crash. Alexis informs them that the ITC staff has managed to recover the systems and is currently trying to recover the data. He gives Hero a data file on a memory chip. It contains a list of five country names, each followed by a number of points (the results from a recent game that Alexis has managed to backup). To unlock this act's puzzle, the player has to run two programs installed on two identical computers of the ITC main room, by plugging the memory chip into each of them and using the data in the chip as input. When plugged into the first computer, the output shown on Fig. 5a is obtained, whereas when plugged into the second computer, different output is obtained (Fig. 5b). The player has the opportunity to speculate on the reason for obtaining different output, and Alexis helps him/her understand why the two computers 'behaved' in different ways (Fig. 6).

Fig. 4 Calculating the current score for each team

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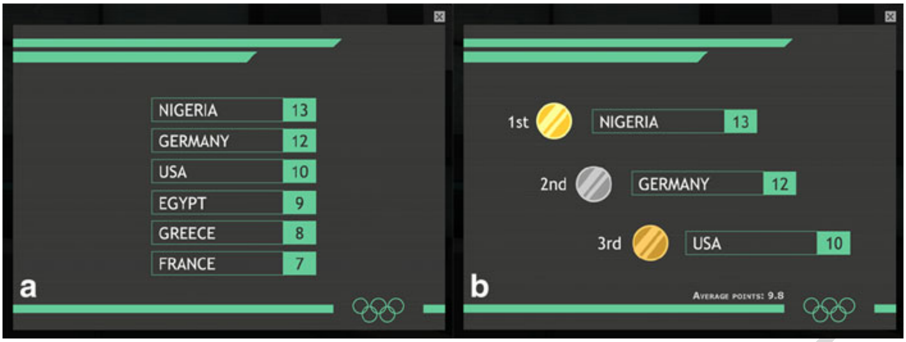

Fig. 5 Output obtained on the two computers of the ITC

Forouzan (2003) points out three cases in the behavior of the programmable data processor: a) same program run with the same input data, b) same program run with different input data, c) different program run with the same input data. Whereas in Act 1 the player runs the same program with different input data, in this act, he/she can run different programs with the same input data, and, thus, enhance his/her practical understanding of the afore-mentioned behavior. Through dialogical interaction between Hero and Alexis, the player is helped to understand what each program does. At this point, Act 2 is concluded, but the player can still poke around the scenario or check the 'Knowledge Database' (implementation of P4, the *'practice principle'*).

3.9 Prototype implementation

The prototype was implemented in ActionScript 3.0 using Adobe Flash CS4. Those tools were chosen due to the easy implementation of graphic elements, the simple coding and the possibility to install the implemented application as a Web browser game. Artwork was produced through Adobe Photoshop and Illustrator, and was

Fig. 6 Alexis explaining the computers' 'behavior'

drawn by one of the authors (R.M.C.) herself. Several images including images from the stock photo website stock.xchng (http://www.sxc.hu/) were used as references or edited into scenarios. The sound effects and music were retrieved from the web portal Flashkit (http://www.flashkit.com/).

4 Evaluation of the prototype

4.1 Purpose

The purpose of the evaluation was: (a) to assess students' responses to the game prototype in terms of appeal, perceived usefulness and basic usability issues, and (b) to investigate the eventual effects of the use of the game prototype on students' knowledge regarding the concepts of input, program, output and their interplay.

4.2 Sample

The sample was 103 first-year DPESS students. Among them, 68 were boys (66% of the sample) and 35 were girls (34% of the sample). The students' mean age was M= 18.97 (SD=3.01). All students used computers in their everyday lives, 20 of them (19.4% of the sample) less than an hour daily, 41 (39.8%) one to two hours daily, 28 (27.2%) two to three hours daily and 14 (13.6%) more than three hours daily. Among the 103 students, 50 (48.5% of the sample) did not play electronic games in their everyday lives, 17 (16.5%) played electronic games less than an hour daily, 31 (30.1%) did so one to two hours daily, 2 (1.9%) two to three hours daily and 3 (2.9%) more than three hours daily.

4.3 Instruments

For the purpose of the evaluation two questionnaires were constructed: a feedback questionnaire and a knowledge questionnaire. These questionnaires elicited both quantitative and qualitative data.

The *feedback questionnaire* was aimed at assessing students' views on the appeal, usefulness and basic usability of the game prototype. Regarding usability, the following two aspects were examined: ease of use and satisfaction from use (Nielsen 1994). This questionnaire first elicited students' biographical data: gender, age, computer use, hours spent on the computer daily, engagement in electronic gaming, hours spent on playing electronic games daily (the results of the analysis of these biographical data have been presented in subsection 4.2). Then, through six 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 game: a) was appealing, b) was easy to use, c) has helped them acquire useful knowledge regarding ICT, d) could help them learn more regarding ICT, e) could help them maintain their motivation for the course, and f) was preferable to traditional learning media for ICT, such as books. Subsequently, through 11 closed questions, students were asked to rate on the same 5-point scale the degree to which they found the following elements engaging: a) the gameplay, b) the user interface,

c) Hero, d) Robot, e) Alexis, f) Staff member, g) the story, h) Act 1 scenario, i) Act 2 scenario, j) Act 1 puzzles, k) Act 2 puzzles. The afore-mentioned 17 closed questions are presented in Table 2, in section 4.6 of this paper (together with the data that emerged from students' answers). Finally, through three open-ended questions, students were asked what they liked the most and what they liked the least about the game as well as to give their own proposals for its improvement.

The *knowledge questionnaire* was aimed at assessing students' knowledge regarding the concepts of input, program and output and their interplay. The questionnaire comprised two parts: the first part consisted of seven semi-closed or closed questions, whereas the second part consisted of one open-ended question. The questions of the first part were as follows. Through the first semi-closed question (Q1), which consisted of three sub-questions, students were asked to complete the three blanks in the following sentence: "The computer receives _ *(choose between 'input' and 'output')* data, processes it according to the _ *(find the missing word)*, and produces _ *(choose between 'input' and 'output')* data. The following six questions of the group were multiple-choice (or 'Yes/No') questions. Through the second question (Q2), students were asked which of the following elements guides the computer in the handling of the data that it receives: a) the memory, b) the program, c) the processor, d) the hard disk. Through the third question (Q3), they were asked whether programmers write programs mostly in: a) machine languages, b) higher-level programming languages. The fourth question (Q4) asked them whether it is possible or not to get different results every time a program is run on the computer. The fifth question (Q5) asked what happens when the same program is run with the same input data (the possible answers were 'different output is obtained' and 'the same output is obtained'). The sixth question (Q6) asked what happens when two different programs are run with the same input data (the possible answers were as in Q5). The seventh question (Q7) asked what happens when the same program is run with two different sets of input data (the possible answers were again as in Q5). Finally, through the open-ended question (Q8), which formed the second part of the questionnaire, students were asked to write, in their own words, what they believed a computer program is.

4.4 Procedure

The research was conducted in the beginning of the academic year 2010–2011, at the DPESS, during the first session of the 'Computers' course, before the students were actually taught any of the course subject matter. A pretest/posttest research design was followed. The knowledge questionnaire was administered to the students twice (before and after their interaction with the game prototype) with a view to assessing the eventual effects of the use of the prototype on their knowledge. The feedback questionnaire was administered to them once, after their interaction with the prototype. Specifically, in the pretest, the knowledge questionnaire was given to the students, after they had been informed about the purposes and the procedures of the intervention. The students completed the questionnaire individually and anonymously. Then, they interacted with the game prototype for about 40 minutes, in the computer laboratory of the DPESS. After they had interacted with the software, the posttest was conducted. In the posttest, the students completed the knowledge questionnaire again followed by the feedback questionnaire (both questionnaires were completed individually and anonymously). For the matching of the questionnaires between the pretest and the posttest, pseudonyms that the students were asked to adopt and note down on their questionnaires were used.

4.5 Data analysis

Students' answers to the closed questions of the feedback questionnaire were analyzed by descriptive statistics. Students' answers to the open-ended questions of the feedback questionnaire were grouped into categories according to their common themes (Gall et al. 1996). Each of the answers was assigned to one or more of the categories (if it had multiple references).

For each student, his/her scores in the two parts of the knowledge questionnaire were calculated as follows. First, a score was calculated for the first part (semi-closed and closed questions). Specifically, in the first question (Q1), each correct word was graded with 1, whereas each erroneous word was graded with 0. Both the words 'program' and 'software' were accepted as correct missing words in the second blank of the question. In the six subsequent questions (Q2 to Q7), each correct answer was graded with 1, whereas each erroneous answer was graded with 0. A student's score in the first part was the sum of his/her grades in questions Q1 to Q7. Possible scores in the first part of the knowledge questionnaire, thus, ranged from 0 to 9, with high scores indicating high levels of knowledge regarding the concepts of input, program, output and their interplay. Then a score was calculated for the second part. Specifically, students' answers to the open-ended question (Q8) were classified by two independent raters into four categories (see Table 1). Inter-judge reliability was 84%. The scoring criteria and respective categories were as follows: a) simplistic and naive responses (category 1—graded with 1), b) responses that comprise elements of scientific thought, but are erroneous (category 2—graded with 2), (c) responses that comprise elements of scientific thought, but are incomplete (category 3—graded with 3), (d) scientifically correct and elaborate responses (category 4—graded with 4). Each student's answer was assigned to one

Table 1 Representative answers to Q8 scored according to the criteria into 4 categories

Category	Answer
1	"The program is necessary for the smooth operation of the computer"
	"The program helps people to solve their everyday problems and facilitate their lives"
2	"The program is the content of the data that are located in the memory of the computer"
	"The program is a device that processes a set of data and exports them to the user"
3	"The program is software that enables us to accomplish a certain task"
	"The program is the steps that the computer follows to process the data that it has received and give correct results"
4	"The program is a set of instructions written in a programming language by the programmer for performing a specific operation on the computer"
	"The program is a set of instructions which determine what the computer will do to the input data so that output data (new information) are obtained from the computer"

of these categories. A program can be defined as a set of instructions that indicate to the computer how to handle the data (Forouzan 2003). Alternatively, it can be defined as a sequence of instructions that enable the computer to perform a specific task (Stair and Reynolds 2003). Students' answers that explained the concept of the program conforming to either definition were judged to be correct and were assigned to Category 4. Possible scores in the second part of the knowledge questionnaire ranged from 1 to 4, with high scores indicating correct and elaborate perceptions regarding the concept of the computer program.

Finally, the eventual impact of the use of the game prototype on students' knowledge regarding the afore-mentioned concepts (input, program, output) and their interplay was investigated through two paired-samples t-tests, which compared students' mean scores between the pretest and the posttest for each part of the knowledge questionnaire. These statistical analyses were performed using the SPSS statistical package. Level of significance was set at 0.05.

4.6 Results

In what follows, the results of the analysis of the (posttest) feedback questionnaire are presented first, followed by those of the pretest and posttest knowledge questionnaires.

4.6.1 Students' view on the appeal and usability of the game prototype

Table 2 presents descriptive statistics, namely means (M) and standard deviations (SD), of students' responses to the game prototype.

As deduced from Table 2, the students of the sample strongly prefer the game to traditional learning media for ICT, and found the game easy to use and its storyline engaging. The means of their answers to the three respective questions were well

Table 2 Students' responses to the game prototype (N=103)

Question	M	SD
The game was appealing	2.79	0.86
The game was easy to use	3.75	1.01
The game helped me acquire useful ICT knowledge	2.97	0.98
The game could help me learn more regarding ICT	2.95	1.01
The game could maintain my motivation for the course	2.96	1.02
The game is preferable to traditional learning media for ICT	3.85	1.16
The gameplay was engaging	2.86	0.99
The user interface was engaging	3.15	0.81
Hero was engaging	2.89	0.94
Robot was engaging	2.94	0.99
Alexis was engaging	2.93	1.05
Staff member was engaging	2.64	1.03
The story was engaging	3.36	1.02
Act 1 scenario was engaging	3.13	0.88
Act 2 scenario was engaging	3.03	0.88
Act 1 puzzles were engaging	3.27	1.07
Act 2 puzzles were engaging	2.99	1.07

above the middle point of the 5-point scale used. The students also found the user interface, the two scenarios and the puzzles engaging, as revealed by the means of their answers to the respective questions, which all were around or above the middle point of the scale. Students' convictions that the game had helped them gain useful ICT knowledge, that it could generally help them learn about ICT and that it could maintain their motivation for the course were relatively less strong. The four game characters were not found to be very appealing, with Staff member being assessed as the least appealing among them. Surprisingly, the students did not find Hero very engaging. Perhaps, this can be explained by the fact that Hero is never shown on the game scenarios as those scenarios are supposed to be seen from the perspective of Hero. The fact that the means of students' answers to the questions regarding the gameplay and the overall game appeal were relatively low suggests that there is much room for improvement of the gameplay in the future so that, hopefully, it will become as engaging as the storyline and the overall game appeal increases.

Students' answers to the open-ended questions of the feedback questionnaire, perhaps, provide more insight into students' views on the prototype.

All 103 students answered the question what they liked the most about the game. Among them, 39 students referred to the game storyline, which, according to them, was engaging and stimulated their curiosity about what would happen next within the game. The fact that the plot was connected to their subject of studies (i.e. sports) was particularly appreciated by those students, who identified with the situations encountered within the virtual environment and with the hero. For instance, a boy wrote *"The plot was interesting and this created curiosity for the continuation of the story. I liked the fact that during the system crash, in a crucial moment of the basketball game, a fellow-student of ours was able to help in solving the problem. It could have been one of us"*. Thirty-six students appreciated the fact that they gained useful knowledge regarding how computers work, in a way that, according to them, was 'active', 'intelligent', 'easy', 'comprehensible' and 'enjoyable'. For example, a girl wrote *"You can easily learn many things about the world of informatics and computers by helping in the evolution of the story. I managed to understand basic facts about computers, which previously seemed too complicated to me"*. Twenty students mentioned in their answers the game characters, and 18 students the puzzles (e.g. a boy wrote *"That we learned about computers by solving puzzles")*. The graphics were mentioned by 10 students, the sounds by 6 students and the interface by 2 students.

Seventeen out of the 103 students answered that there was not anything that they did not like about the game prototype. Of the remaining 86 students, 25 mentioned the fact that the game contained too many dialogues, which they found tiring. Twenty-three students made various comments regarding the characters (e.g. a boy wrote *"That Hero does not appear to us at any point of the game"*). Surprisingly enough, certain students mentioned that they found the Robot's dialogues with Hero disruptive. Sixteen students mentioned that the puzzles were not challenging enough. For instance, a girl wrote *"The puzzles were simple enough for me. I think that the user could have more things to do, that is to say, to participate more actively"*. The storyline was mentioned by 14 students, who would have preferred a plot of greater duration, the graphics by 5 students, the interface by 5 students and the sound by one student.

Finally, 51 students made proposals for the improvement of the game. Among them, 28 proposed that it should be enriched with more puzzles, which should be as challenging as possible, and with more opportunities for active user involvement. This proposal was sometimes coupled with a suggestion for fewer and shorter dialogues. For example, a boy wrote *"More puzzles to solve, more activities and fewer dialogues"*. And a girl wrote *"That the game puzzles become a little bit more complicated and more difficult so that players' interest is spurred and their participation is more substantial. The dialogues should be shorter and more interesting so that the player is kept in suspense"*. Eleven students mentioned that the storyline could be of greater duration. An improvement to the graphics (by adding animated and/or three-dimensional graphics) was also suggested by 11 students. Finally, 8 students proposed improvements to the characters (e.g. a boy asked for more characters and a girl for a female character).

From the findings presented in this subsection, it can be deduced that, overall, most game elements elicited average to positive responses from the students. The game's stronger elements, as seen by the students, were its comparatively greater appeal to traditional learning media for ICT, its ease of use and its engaging and meaningful for them—though short—storyline. The weakest elements were the game's characters, who engaged in lengthy dialogues, and the gameplay, which could include more challenges and could demand more active involvement from the player.

4.6.2 Impact of the game prototype on students' knowledge

Table 3 presents students' scores on the two parts of the knowledge questionnaire in the pretest and in the posttest.

As deduced from Table 3, the paired-samples *t*-test that compared students' mean scores in the first part of the knowledge questionnaire, between the pretest and the posttest, showed that there was a statistically significant increase in students' scores on the first part of the questionnaire from the pretest to the posttest. The eta squared statistic indicated a large effect size (Pallant 2001). The same analysis, performed on students' pretest and posttest mean scores in the second part of the knowledge questionnaire (open-ended question), also showed that there was a statistically significant increase in students' scores on the second part of the questionnaire from the pretest to the posttest. The eta squared statistic indicated again a large effect size. It can, thus, be deduced that interacting with the game prototype significantly improved students' knowledge regarding the concepts of input, program and output and their interplay, and hence students' understanding of the basic functions that a computer performs.

Table 3 Pretest and posttest scores on the knowledge questionnaire (N=103)

Knowledge questionnaire	Pretest		Posttest		Difference		
	M	SD	M	SD	t(102)	p	eta squared
First part (semi-closed and closed questions)	7.28	1.35	8.10	1.15	−6.459	<0.001	0.29
Second part (open-ended question)	2.05	0.84	2.59	0.91	−5.889	<0.001	0.25

The results of the analysis of the open-ended question (Q8) deserve a closer look because they reveal students' discourse and perceptions regarding what a computer program is, as well as the effects that students' interaction with the game prototype had on these perceptions. Table 4 shows the frequencies and percentages of students' answers to Q8 (in the pretest and the posttest) as they were classified into the four categories.

As deduced from Table 4, in the pretest, 69.9% of the students gave answers that revealed perceptions that were either naïve/simplistic or erroneous, whereas only 30.1% of the students gave answers that either contained elements of scientific thought (but were incomplete) or were scientifically correct and elaborate. In the posttest the respective percentages were 50.5% and 49.5%, which indicates that the game had a positive effect on students' perceptions regarding the concept of the program, given that after having used it, about half of the students had fully or partially understood what a computer program is.

Examples of students' answers to Q8 which reveal positive changes in students' perceptions are presented in what follows.

For instance, in the pretest a girl wrote that a computer program is *"A desktop where the user can place various programs that have to do with sound, video, games, etc."*, an answer that was erroneous and was classified into Category 2. In the posttest, the same girl wrote *"A program is a set of instructions through which specific tasks are executed on the computer"*, a correct explanation, which was classified into Category 4.

Another girl's answer in the pretest (*"The program is the element that processes the data that we enter to the computer"*) revealed that she believed that the program itself processes the input data, and was classified into Category 2. This identification of the program with the central processing unit is a common misconception that was detected in students' discourse. In the posttest, the same girl gave an answer which was classified into category 4 and which revealed that she had understood that the program itself does not process any data, but provides the instructions that are necessary for the processing of data (*"The program provides the computer with instructions on how to use the input data in order to produce output data"*).

A boy answered in the pretest that *"The program is a set of data"*, an erroneous answer which was classified into Category 2 and which demonstrates another common misconception detected in students' discourse, namely an identification of the program with the data that the computer processes according to the program. The same boy, in the posttest, answered that the program is *"A set of instructions through which the computer performs a specific task"*, a correct answer that was classified into Category 4.

Table 4 Students' answers to Q8 in the pretest and the posttest (N=103)

Category	Pretest		Posttest	
	f	%	f	%
1	30	29.1	10	9.7
2	42	40.8	42	40.8
3	27	26.2	31	30.1
4	4	3.9	20	19.4

Another boy in the pretest wrote that the program is *"A computer application created to perform specific tasks"*, an answered which was assigned to Category 3. The answer that the same boy gave in the posttest (*"It is series of instructions for the computer to perform specific operations. The user can run a program entering data and gets specific results"*) was more complete and elaborate and was assigned to Category 4.

On the whole, among the 42 students that were found to initially have various misconceptions (and their answers were assigned to Category 2 in the pretest), in the posttest, two gave simplistic or naive responses (Category 1), 26 continued to have erroneous conceptions (Category 2), four gave responses that comprised elements of scientific thought but were incomplete (Category 3), and 10 gave scientifically correct and elaborate responses (Category 4). Thus, 14 out of the 42 students (i.e. one third of them) were helped by the game to overcome their misconceptions.

As derived by the findings presented in this subsection, the use of the game prototype had a significant positive effect on students' knowledge regarding the concepts of input, program, output and their interplay. The game also helped students form more mature, scientifically correct and elaborate mental conceptions regarding what a computer program is and how the program guides the functioning of the computer.

5 Discussion & conclusions

This paper presented the prototype of the introductory part of a computer game designed according to constructivist learning principles and aimed at introducing physical education and sport science undergraduate students to basic ICT concepts. Furthermore, the impact of its use on students, in terms of appeal, basic usability issues and learning outcomes, was investigated through conducting an evaluation study in real academic settings, on a large sample of students of the intended target group.

According to the results of the evaluation, the game prototype was well-accepted by the students as an alternative learning tool for ICT, and most game elements elicited average to positive responses by the students. The latter found the game easy to use and appreciated its storyline, which they found meaningful because of its connection with sports, their subject of studies, although of limited duration. The game user interface, scenarios and puzzles were found to be engaging, but at the same time, students expressed an eagerness for better gameplay, better characters, less lengthy dialogues between characters and more challenging puzzles, so that the player's active involvement within the game increases, rendering the game more appealing for them.

The specific learning objective of the game prototype was to help the students form an appropriate mental model about how a computer works, namely to conceive the computer as a programmable data processor, get introduced to the basic concepts of input, program and output and understand their interplay. The results of the evaluation showed that the prototype had a significant positive effect on students' knowledge regarding these concepts and their interplay, and that it helped certain students overcome various misconceptions that they initially had (e.g. identification of the program with the central processing unit or with the data), and form more scientifically acceptable and elaborate mental conceptions about the basic functions of the computer.

The afore-mentioned findings are encouraging overall and seem to support the findings of prior research (Virvou et al. 2005; Connolly et al. 2006; Hingston et al. 2006; Tüzün 2007; Srinivasan et al. 2008; Milone et al. 2009; Papastergiou 2009a; Sindre et al. 2009; Kordaki 2011), which has shown that DGBL environments are appreciated by students, and enhance student learning.

The findings of the conducted evaluation should be taken into account for the future improvement and extension of the game. Specifically, on the basis of these findings, the following changes should be made to the game with a view to enhancing its appeal and learning effectiveness: a) the game should be extended to comprise more acts and more levels, according to a storyline of greater duration, b) the learning objectives of and topics covered by the game should also be extended and, accordingly, more puzzles of progressively higher degree of difficulty should be incorporated, c) the text-based dialogues among the characters should be limited (e.g. the information conveyed through them could be provided through brief animations based on comic-styled scenes, which would keep the player informed about the progress in the storyline), d) the game characters should be revised (e.g. Hero's presence could be strengthened, through switching from first person to a third person perspective, so that students relate with the character even more), and e) players' active involvement should be further encouraged, namely, players should be granted more freedom and more opportunities to experiment with the concepts presented in the game and construct their knowledge. Regarding the latter: although effort was made that the fundamentals of the constructivist learning approach be present in the game design (e.g. students were allowed to explore the virtual environment, interact with objects and learn from their experience), the basic principles of this approach, which were outlined earlier in this paper, should be better reflected in the game design and, specifically, in the way the player's activity takes place within the game environment.

Apart from those improvements to existing features of the game, the following additional future features could also be devised: a) a mechanism for storing students' game progress online so that the instructor can consult it remotely, b) character personalization by the student (e.g. possibility to create a female counterpart of Hero and to add custom names to characters), and c) a multiplayer mode, which could encourage interaction and collaboration among students during the puzzle-solving process.

As deduced from the evaluation results, and in agreement with the findings of prior research (e.g. Virvou et al. 2005; Papastergiou 2009a), students have high expectations regarding a DGBL environment (e.g. in the present study, certain students asked for three-dimensional graphics), and they often expect to find in such an environment the compelling and captivating features that they encounter in the commercial games that they play in their everyday lives. However, it should be acknowledged that the creation of a truly engaging game with multiple levels, a coherent walkthrough, sophisticated graphics and gameplay, to be played during an entire academic semester, is an extremely difficult and time-consuming task (Tüzün 2007). Perhaps, such a task cannot be undertaken by researchers in academia alone, but by interdisciplinary teams formed by such researchers, and also multimedia designers, computer programmers and game developers (Tüzün 2007; Papastergiou 2009b).

The work presented in this paper had certain limitations which should be mentioned. Firstly, the game prototype had a storyline of limited duration and only a few, introductory puzzles. The results of the evaluation might, perhaps, have been different if a greater part of the game was implemented and the students had interacted with the software for a longer period of time. Secondly, in the conducted evaluation there was no control group. Obviously, having a control group of students who would be introduced to the same concepts (as those addressed in the game) through, for instance, a traditional lecture would have rendered the study more valid. However, the authors' intention, at this stage of game design and development, was not to conduct a control trial, but to elicit students' preliminary responses to and learning outcomes from the use of the game prototype within a naturalistic academic setting.

This study opens up interesting research perspectives. First of all, it is worth improving and extending the game as described earlier in this section. Once the game is enriched with a longer storyline and additional challenges (so that it can be used for a longer period of time by students), it will be interesting to assess it again as to its appeal, usability and learning outcomes, this time following an experimental design that includes a control group, as described in the previous paragraph. A particular feature that, perhaps, deserves to be further researched on its own is the multiplayer mode. An interesting research question is how this mode could be implemented within the game so that it promotes knowledge construction through students' interactions, a basic tenet of the constructivist learning approach, at the same time promoting challenge and even competition, which are elements that users value in multiplayer games (Thomas 2011). Furthermore, once the multi-player mode is implemented, it would be interesting to investigate, through a control trial, which game mode (single-player or multi-player) yields greater student engagement and better learning outcomes.

The contribution of this paper is that it provides a concrete case study on the design and evaluation of an educational game for the learning of ICT concepts by students of a non ICT-oriented academic discipline (namely, physical education and sport science). The paper demonstrated that it is feasible to create such a game and that the integration of the ICT concepts under study into a storyline and challenges inspired from the students' academic discipline is crucial for the acceptance of the game by the students. It is hoped that the paper provides useful guidance to researchers and practitioners who are involved in the teaching of ICT to students enrolled in disciplines not directly related to ICT as well as to game designers who might be interested in creating games for the learning of ICT concepts by various target groups.

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AUTHOR QUERIES

AUTHOR PLEASE ANSWER ALL QUERIES.

Q1. The citation “Kirremuir and McFarlane 2004” (original) has been changed to “Kirriemuir and McFarlane 2004”. Please check if appropriate.

Q2. “Kiili 2000a” is cited in text but not given in the reference list. Please provide details in the list or delete the citation from the text.