GAME-ENHANCED MATHEMATICS LEARNING FOR PRE-SERVICE PRIMARY SCHOOL TEACHERS

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Abstract

The article reports the main insights gained from a study that implemented a game-enhanced learning environment for the training of pre-service elementary school teachers. Teachers taking an undergraduate mathematics methods course experienced some of the ways in which online educational games could help students internalize key mathematical concepts across the school curriculum while at the same time improving their attitudes towards the subject. The course also familiarized teachers with the design principles for constructivist gaming environments. Findings indicate a positive impact on teachers' competence in selecting, evaluating, and productively using online games as an instructional tool.

Introduction

Empirical classroom research over several decades shows that, with some notable exceptions, mathematics instruction has been characterized by traditional, abstract formulation which seems to be readily understood by only a small fraction of students (Mor et al., 2006). The teaching of mathematics is viewed as unappealing to the majority of students, as outdated and unconnected with their interests and experiences (Goodrum, Hackling, & Rennie, 2001). Ideas are presented in an overly theoretical and abstract manner without sufficient opportunities for students to engage in problem solving and experimentation (Euler, 2011).

Technological advances have provided the opportunity to create an entirely new learning environment in mathematics by significantly increasing the range and sophistication of possible classroom activities. Access to technology provides teachers and students with tools which, when constructively used, can create opportunities for enhanced learning of mathematics. Although traditional, teacher-centered approaches to mathematics instruction still dominate (European Commission, 2007); there have been several attempts to improve mathematics instruction through the integration of learning technologies. One promising approach explored is the potential of computer games as tools for supporting mathematics teaching and learning. The literature indicates strongly the educational value of using games within mathematics education (e.g., Resnick et al, 1996; Jonker & van Galen, 2004).

The current paper contributes to the emerging literature on game-enhanced mathematics teaching and learning. It reports on the main experiences gained from a study which aimed at providing a group of pre-service primary school teachers with the knowledge, skills, and confidence required to incorporate game-enhanced learning within the mathematics curriculum.

Literature Review

Research suggests that use of educational games is an effective means of improving students' attitudes towards mathematics. It has been shown that educational games attract and gain students' attention, contributing to their increased motivation and engagement with mathematics (e.g., Squire, 2005; Young-Loveridge, 2005; Ke, 2008). Although much of the research on the effectiveness of gaming on learning is inconclusive at this point (Fletcher & Tobias, 2006), there is strong evidence that appropriately designed educational games do have the potential to enhance children's learning of mathematics (e.g., Klawe, 1998; Bragg, 2007; McGivern et al., 2007; Simpson et al, 2006). Through the introduction of challenging tasks that are meaningful for children and facilitate their interest in exploration, educational games can help focus mathematics instruction on conceptual understanding and problem-solving and not on recipes and formal derivations, which become secondary in importance. Through use of educational games, children can build valuable skills such as strategic thinking, planning, communication, the application of numbers, negotiating skills, group decision-making and data-handling (Kirriemuir & McFarlane, 2004; Pratt et al., 2009).

One of the most important factors in any educational change is the change in teaching practices. The direct relationship between improving the quality of teaching and improving students' learning in mathematics is a common thread emerging from educational research (Stigler & Hiebert 1999). For it is what a teacher knows and can do that influences how she or he/she organizes and conducts lessons, and it is the nature of these lessons that ultimately determines what students learn and how. Educational games' successful deployment in mathematics classrooms is highly dependent upon the knowledge, attitudes, and experiences of teachers with respect to games. Thus, the provision of high quality teacher professional development on the educational applications of games is of paramount importance to their effective integration in classroom settings.

Study Methodology

In the current study, a teaching experiment took place within an undergraduate mathematics education course targeting primary school pre-service teachers at a private university in Cyprus. The teaching experiment aimed at promoting, while at the same time also investigating, students' efficacy in effectively selecting and integrating digital games within the mathematics curriculum.

Conceptual Framework

The design of the study was guided by the technological, pedagogical content knowledge (TPACK) conceptual framework (Mishra & Koehler, 2006). The TPACK framework, which builds on Shulman's (1986) idea of Pedagogical

Content Knowledge, emphasises the importance of developing integrated and interdependent understanding of three primary forms of knowledge: technology, pedagogy, and content. The framework is based upon the premise that effective technology integration for pedagogy around specific subject matter requires developing understanding of the dynamic relationship between all three knowledge components. Thus, teacher ICT training cannot be treated as context-free, but should be accompanied with emphasis on how technology relates to the pedagogy and content. The aim is to move teachers beyond technocentric strategies that focus on the technology rather than the learning (Harris, Mishra, & Koehler, 2009).

Research Design: Scope and Context of Study

A case study design with mixed methods was employed in the study. The case studied consisted of a group of 13 students (10 females, 3 males) enrolled in the undergraduate methods course *Integration of Modern Technology in the Teaching of Mathematics*, which includes a unit on game-enhanced learning. Students were mostly in the final year of their studies. The mean age of the students was 22 years.

Acknowledging the fact that teachers are at the heart of any educational reform effort, the course was designed to offer high-quality professional development experiences to these learners that would enable them to effectively integrate technology with core curricular ideas. The emphasis was on enriching students' technological pedagogical content knowledge (TPACK) of mathematics by providing them with opportunities to develop their knowledge, skills, and attitudes towards technology-enhanced mathematics learning.

The unit on game-enhanced learning, which lasted for three weeks (9 hours), introduced students to the rationale and context for employing digital games in mathematics classrooms. They experienced some of the ways in which online educational games could help students internalize key mathematical concepts across the school curriculum while at the same time improving their attitudes towards the subject. The unit also familiarized students with the design principles for constructivist gaming environments (Munoz-Rosario & Widmeyer, 2009), and promoted the development of their skills in properly evaluating educational games available online, and in selecting games with pedagogically-sound design features.

Instruments, Data Collection and Analysis Procedures

Multiple forms of assessment were used to collect and document evidence of changes in students' technological pedagogical content knowledge (TPACK), and in their attitudes towards game-enhanced mathematics instruction as a result of participating in the course: a pre-survey, audio-recordings of class sessions, video-records of group activities, interviews of individual students, samples of student work, and classroom observations.

Analysis of the collected data has provided rich insights into teachers' perspectives on game use and its effectiveness, and into the ways in which the course influenced these perceptive, as well as their confidence and ability to incorporate game-enhanced learning within the mathematics curriculum. The next section will share some of these insights.

Results

Prior Experiences and Attitudes Towards Games

An online pre-survey completed in class by all course participants (*n=13*), and follow-up interviews of some of the participants (*n=5*), provided baseline information regarding the students' prior experiences and attitudes towards game-based mathematics learning.

The majority of the students were quite facile with digital games. They had considerable experience with both single player games (e.g. Temple Run, Pro Evolution Soccer, Run Tekken, Soulcalibur), and with multiplayer games available on Facebook such as Diamond Dash and Bubble Island. This finding was not surprising given the students' young age. All of them were *digital natives* who grew up surrounded by technology and who had been playing video games since the time they were children.

Playing of games was an important leisure time activity for almost all of the students. Nine students reported playing games on a daily or weekly basis in their spare time, while two others reported playing *games* "a few times per month." Despite the small number of participants involved in the study, there was considerable breadth of game-based activity. Most of the students spent between 4-6 hours per week on games, but two of them were keen games players who spent at least 10 hours per week on games. At the same time, however, there were two students who reported rarely playing any games because they considered it to be "a waste of time."

In the pre-survey and follow-up interviews, students were asked to express their opinion regarding the use of digital games in mathematics education, and to state whether they would consider incorporating such games in their teaching in the future. All of the students agreed that games should be considered as worthy of consideration in the classroom and indicated that they planned to utilize gaming in their teaching. Despite, however, their positive attitudes toward the use of games in education, students made comments that suggested very limited knowledge and experience with game-based instruction, and lack of appreciation of the potential of digital games to transform the nature of mathematics instruction. Students viewed games mainly as a useful aid for making mathematics instruction more joyful. The most commonly cited reasons for considering using games in the classroom were for increasing students' motivation and engagement. Responses such as the following were typical: "Games allow teachers to make their lessons more interesting and children to learn without getting bored"; "It's more fun for children... They all love playing electronic games at home. Gaming in the classroom provides a strong incentive for children to actively participate in the learning process"; "It's a powerful way to attract all children's attention and to help them learn mathematical concepts more easily."

When, in the follow-up interviews, students were prompted to identify opportunities for introducing games in the mathematics classroom, it became obvious that they had a very limited notion of game-based instruction. They viewed games as tools for practicing and/or evaluating acquired skills, and not as a powerful means of creating immersive learning experiences that would otherwise be impossible or too costly or too dangerous to provide to students (Mitchell & Savill-Smith, 2004): "I don't think it would be a good idea to use digital games for introducing a new concept or idea. I believe that games should be used at the completion of a unit for students to practice what they have been taught." "The teacher can use games at the completion of a lesson for summative evaluation purposes, in order to see whether his/her learning objectives have been achieved."

Students' restricted view of games seems to have stemmed from the fact that their past exposure to digital educational games in mathematics had been limited to drill-and-practice ones, as their comments indicated: "An example of a good educational game in mathematics education is one where children are asked to write the fraction corresponding to the highlighted portion of a shape." "Children can use games to practice doing addition, subtraction, multiplication and division." None of the students had ever been exposed to a challenging, complex and scaffolded (Gee, 2003) educational game designed to help students build higher order mathematical problem-solving skills.

Nature of Teaching Experiment

Findings from the pre-survey and follow-up interviews pointed to the clear need for students' professional training on ways to effectively use digital games as a pedagogical tool. Despite their extensive prior experience and knowledge of playing games for their own leisure, students had very limited understanding of the educational potential of games, and of how to implement game-based mathematics instruction. The teaching experiment aimed at helping them develop a more sophisticated view regarding the benefits of gaming than their instrumental view of games as "providing the 'fun' incentive for young people to pay attention in lessons" (Williamson, 2009, p. 31). Students were offered a critical introduction into the potential and challenges of using computer games in mathematics instruction, and into the ways in which purposefully selected games blended with carefully constructed learning experiences can be used to turn children into reflective and self-directed learners and to improve their learning of mathematics.

Students worked in group activities to explore a variety of mathematical concepts using online educational games. Through experimentation with a range of games platforms and software, feedback from each other and reflection, they gained better understanding of how digital games could be integrated into the mathematics curriculum. They also improved their ability to assess the educative power of different games, to properly identify their advantages and disadvantages.

In addition to computer activities, there were also discussions focusing on children's learning and what is required to involve them in learning about mathematics though use of educational games. These discussions provided the venue for discussing the affordances and limitations of educational games, and for identifying design considerations and implementation strategies that promote the incorporation of online educational games in ways that motivate children, and help them build a solid foundation in their mathematics skills.

A characteristic example of the type of activities in which students engaged during the instructional experiment is the "Evaluation of Educational Games" Task described next.

***"Evaluation of educational games*" task.** In this group activity, students worked together to compare and contrast different online educational games. They were provided with a long list of different educational games freely available online, from which they had to select two games: a good example of a high quality mathematics education game, and a poor example. Students had to write a report justifying the rationale for their choices. We describe next how two of the students, George and Anna, approached the task.

After experimenting with several educational games, George and Anna finally selected the game "Crack Hacker's Safe" as a good example of a high quality educational game. "Crack Hacker's Safe" can be found on Cyberchase, an award-winning, research-based website offered by Public Broadcasting Station (http://pbskids.org/cyberchase/math-games/crack-hackers-safe/), which has been designed for children ages 8 to 12 to "deliver positive messages about math by teaching concepts in a fun way that kids can understand." The Cyberchase website has several dynamic web games packed with mystery, humor, and action that can help children build strong mathematics and problem-solving skills while exploring their world. In "Crack Hacker's Safe," the players "must help Digit crack the lock on Hacker's safe." They must complete a sequence of shape, number and color patterns to crack the code on the hacker's safe and open the lock (see Figure 1 below). The game aims at building students' algebraic reasoning through the identification of both growing and shrinking patterns. Children can play the game individually or with friends and classmates.

Figure 1. The "Crack Hacker's Safe" online game.

In their report, George and Anna gave several reasons for positively evaluating the specific game, including the following:

- The game interface is user-friendly, with well designed graphics and easy to learn game functionalities.

- A Help section is available during the game to assist children that require extra help.
- The game addresses important mathematical content and concepts – the development of algebraic reasoning through pattern recognition
- The game has clear goals and objectives to be accomplished by the player in order to complete the game: “Children aim at completing a series of shape, number and color patterns to crack Hacker's safe.”
- The game has a good scenario: “The game does not simply ask students to recognize some mathematical patterns. Children assume the role of a hacker and they try to find the right combinations to unlock the safe. This is an interesting and challenging scenario that can easily attract children’s attention and increase their motivation.”
- The game focuses on high-level mathematics learning rather than on factual recall, developing students’ critical thinking and problem solving skills.
- The game advances in a step-by-step fashion, providing a challenging problem-solving environment for children.
- Each student attempt is followed by appropriate feedback. If necessary, hints are provided to the player to help him/her solve the problem.
- Players are recognized as winners only if important learning takes place: “To find the right combination and open the safe, children need to decode complicated patterns that combine numbers, colors, and shapes. Thus winning cannot be the result of random selection, but has to be based on real understanding of the underlying patterns.”
- The game can support collaboration and group work: “The teacher can ask children to play the game in pairs in order to promote interaction among students and teamwork.”
- The game can support competition: “Although the game interface is not multiplayer, if the game is played in class, then the teacher can increase students’ motivation and help them develop their competition skills by asking them to work in pairs, with the winning team being the one that accomplishes to unlock the safe first”.

The game selected by George and Anna as a poor example of an online educational game was “Tumbletown Mathletics.” Review it at: http://www.tvokids.com/games/tumbletownmathletics. Tumbletown Mathletics is comprised of five “mini-games” which aim to help children develop their numeration and measurement skills by practicing mathematics “in a fun and exciting way.” These games are based on the Ontario school curriculum. Children accumulate points through mathematical activities such as ordering numbers, finding fractions, adding and subtracting *numbers*, and making measurements using non-standard and standard units. The goal is for children to beat their last score (see Figure 2).

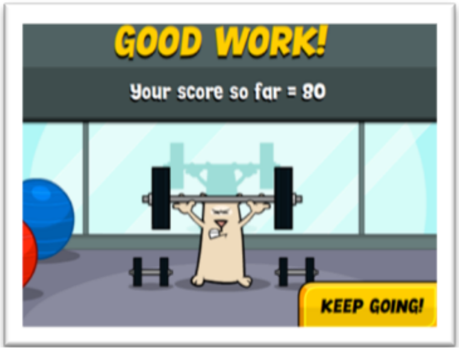

Figure 2. The “Tumbetown Mathletics” online game.

George and Anna noted that although “Tumbletown Mathletics” does have a user-friendly and well-designed interface, it is not a game they would introduce in their mathematics classroom. They gave several reasons to justify their negative evaluation of the game:

- The game does not provide proper feedback: “When the player gives a wrong answer, the system just lets them know that their answer is wrong. No other feedback is provided to help children understand why they are wrong.”
- The game is not based on any scenario: “The game does not have any plot. All the child does is to try to beat the score they got the previous they played the game.”
- The game is not challenging and engaging: “The game is too easy. It is not motivating and children will get bored easily.”
- The game can only be played individually, thus there is no opportunity for collaboration and/or competition among children.
- It is a drill-and-practice game: “The questions that students have to answer assess only procedural knowledge and not higher order thinking. The game can be used for drill-and-practice purposes, but not for building students’ problem solving skills.”
- Finding the right answer can be based on random factors: “The questions posed by the game are multiple choice questions with only two possible choices, so children can get the right answer by chance.”

George and Anna based their evaluation of the two games on important technical and pedagogical considerations. Similarly to all of the other students participating in the study, while initially they tended to focus almost solely on the playfulness of games, they have now come to recognize the need for educational games to combine playfulness with instructional soundness (McDaniel & Telep, 2009).

Concluding Remarks

In technology-based society, where mathematics provides essential knowledge tools and the foundations for more advanced and specialized training for both higher education and lifelong learning, cross-national studies of student achievement (e.g., Trends in International Mathematics and Science Study [TIMSS], Programme for International Student Assessment [PISA]) indicate the lack of mathematical and scientific competence of considerable proportion of both the adult and student population around Europe and internationally. There is also well-documented evidence of declining interest in key mathematics and science topics and careers (Rocard et al., 2007). The decline in interest is of concern given that mathematical literacy serves as one of the foundational areas of knowledge that drives scientific and technological advancement in knowledge-based economies.

The methods of teaching mathematics in schools have been identified as contributing to the falling interest in mathematics (Rocard et al., 2007). The current study represents an effort to address declining interest in mathematics, and to raise the educational standards of students in this discipline. It exploits the affordance of digital games in an effort to spark young children’s interest in mathematics and to make mathematical concepts more accessible and attractive for all children.

Recognizing the central role of teachers in educational reform, a teaching experiment took place within an undergraduate mathematics methods course, aimed at empowering the participating pre-service primary teachers to effectively integrate digital games within the mathematics curriculum. The teaching experiment offered a critical introduction into the potential and challenges of game-enhanced mathematics instruction.

Findings from the study indicate that the teaching experiment helped this group of young educators move beyond their initial view of digital games as tools to be used “for their own sake or for flimsily conceived incentivisation purposes” (Williamson, 2009, p.31). Through experimentation with a variety of educational games, prospective teachers were familiarized with the design principles for constructivist gaming environments. They became much more competent in selecting educationally sound games that include the elements of collaboration and competition, and promote authenticity of learning, inquiry learning, reflective thinking, and mathematical problem solving.

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