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An initial study of educational game applications supporting the STEM education in K-12 systems

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[Research in Progress]

Abstract

This study develops a novel model focusing on educational game development based on active learning paradigm. The model is designed as a collaborative endeavor involving college constituencies and K-12 stakeholders in the effort to promote adoption of educational game applications supporting the STEM curriculum in K-12 systems. Preliminary evidence from pilot experiments suggest that college students found real-world game development activities stimulating and worthwhile while K-12 administrators and teachers became interested in game development collaboration. Based on this initial success, an educational game laboratory model is proposed. The model explains the roles played by different actors in the collaborative effort. It also outlines a set of expected outcomes for an ensuing experiment. Finally, the model specifies potential evaluation schemes. The results obtained from the experiment would present further evidence concerning the effectiveness of educational games. In particular, the study could potentially provide insights and directions for game developers in the areas of technical features, content selection and delivery methods.

Keywords: Active learning, gamification, game-based learning, educational game laboratory model, STEM curriculum, K-12 systems

Introduction

A fast evolving, technology-driven modern society increasingly needs well-trained science, technology, engineering and mathematics (STEM) workforce equipped with innovative problem solving and higher-order thinking skills. The goal of our proposed research is to design and develop game-based mobile educational applications in collaboration with educational researchers and K-12 stakeholders. The game applications will help K-12 educators in a 18-county region in the southeastern US (the Region) teach STEM curriculum requiring the factual knowledge such as facts, jargon, and terminology and the conceptual knowledge required to conceptualize the problem domain by providing the appropriate content at the different levels of learning. We believe that these game-based mobile educational applications can help K-12 students successfully obtain the required knowledge and become well-trained STEM workforce with innovative problem-solving skills to play a key role in the economic development in the Region in the future.

The proposed program is based on the tenets of the literature on active learning which advocates a dual approach to learning combining an exposure to theoretical knowledge and hands-on, practical applications of essential concepts (Mengel & Bowling, 1995; Ausubel, 1968; Cigas, 2002; Imboden & Strothmann, 2010). The program focuses on the idea of engaging college students in the development of educational game applications and subsequent testing the resultant products in K-12 systems. According to Kapp (2012), an instructional game application is “a system in which players engage in an abstract challenge, defined by rules, interactivity, and feedback, that results in a quantifiable outcome often eliciting an emotional reaction” (p. 7). Instructional games and simulation games are terms that are used interchangeably in the literature. A meta-study of the literature related to the instructional effectiveness of simulation games developed by Sitzmann (2011) revealed that simulation games present an effective learning tool evident in a number of outcomes. First, trainees learning through video-gaming tools reported a 20% higher level of self-efficacy versus a comparison group which used other methods of instruction. Also, they scored 11% higher on declarative knowledge whereas their scores on procedural knowledge were 14% higher. Finally, retention (of declarative knowledge) stood at a 9 % higher mark for trainees using simulation games versus a comparison group.

The explicit impetus behind this study is to promote active-learning methods such as game-based learning by identifying specific features, components, content and embed them into educational game applications potentially making K-12 students more stimulated to embrace the STEM curriculum. This effort is timely as a labor market nationwide experiences a shortage of qualified personnel to fill in technology-related positions (Georgia Partnership for Excellence in Education (GPEE), 2013). The New Media Consortium, an organization focusing on research in the area of educational technology, named game-based learning as one of the six emerging instructional technologies to watch (Johnson, Adams & Cummins, 2012). The report prepared by The New Media Consortium in 2012 forecasted that game-based learning would come into mainstream use in K-12 systems in the timeframe spanning from two to three years (Johnson et al., 2012).

To facilitate the adoption of game-based learning in K-12 public schools in the Region, we aim to identify a number of educational game applications which would serve as models for developing solutions specific to the needs of a particular school district. Additionally, we want to develop a rubric which would include a number of indicators designed to evaluate the effectiveness of proposed games. Finally, we want to propose an experiment aimed to put to test a suite of game applications targeting a number of school districts in the Region. In this paper, we propose a model for a large-scale game development experiment built on initial empirical evidence gathered from the projects completed by undergraduate students. This anecdotal evidence will be used to make a case for a larger study.

The remainder of this paper is organized as follows. First, we develop a theoretical framework by discussing the insights from major literature streams that contribute to the development of our research model and experiment. Next, we will present and discuss the results of pilot experiments concerning the development of educational game applications which build a case for a larger experiment. We then move to specifying our research model and details of the experiment we are proposing. Finally, we will present a set of conclusions for this research endeavor.

Active-learning Paradigm and Gamification

There is an acceptance in academia amongst researchers on the value of supplementing theoretical knowledge with hands-on activities that are designed to engage students' learning experiences (Mengel & Bowling, 1995; Ausubel, 1968; Cigas, 2002; Imboden & Strothmann, 2010). Previous research (Kinsley, 1993; Kinsley, 1994) indicated that there are numerous benefits to hands-on or active learning, including improved critical thinking and problem-solving skills, the ability to apply knowledge in related situations, and increased student interest and motivation. Active learning is a broad term used to describe several different methods of instruction in which the learner is responsible for their own learning. Active learning has its roots in the constructivism learning theory (Dewey, 1938; Piaget, 1972; Vygotsky, 1978; Bruner, 1990) whereby the learner or student actively constructs information rather than passively receiving information from the environment.

Bonwell and Eison (1991) have contributed largely to the development of active learning and to its acceptance of a viable approach. Active learning includes practices such as group discussions, laboratory experiments, games or game-based learning, debates, and role play (Bonwell & Eison, 1991). Active learning uses problem-based learning. In a meta-analysis conducted by Vernon and Blake (1993), student attitudes, class attendance, and student moods were found to be consistently more positive than those of students in courses that used only the traditional lecture approach to teaching and learning. Educational games and simulations are excellent active learning tools that have been gaining attention recently because they enhance students' participation and decision-making throughout the learning process, and they allow practicing real-life behaviors in a realistic environment (Zapalska, Brozik, & Rudd, 2012).

Game-based learning is a part of a broader movement labeled gamification. The latter term refers to using game-like elements in non-game contexts to promote learning as well as help the learner engage in problem solving (Kapp, 2012). It has been reported that these gamification techniques can help successfully deliver the different levels of knowledge at the different stages. To obtain its benefits, however, a given educational game needs to be carefully designed and effectively implemented to successfully engage students in the learning process. For example, students who lack the factual knowledge or an understanding of the basic concepts needed to perform certain higher level procedures cannot be immersed into an educational game that focuses on teaching only the procedures.

It is believed that the innovative STEM workforce can be well-trained by receiving the adequate level of scientific knowledge such as facts, concepts, rules and procedures at suitable learning stages. Researchers have developed classification schemes to define different types of knowledge and these schemes can be used to help adequately implement the design of educational programs focusing on the proper scientific knowledge (Kapp, 2012; Alavi & Leidner, 2001). Usually, declarative or factual knowledge, which can be learned through memorization, is believed to be taught first because, without the factual knowledge, higher levels of knowledge, like advanced problem solving, cannot be acquired. Once facts are clearly learned, then concepts, which are groups of related ideas that have common attributes, can be understood easily (Kapp, 2012). Then other kinds of knowledge, such as rules, procedures, strategies, and so on can be obtained.

Finally, the combination of all these types of knowledge can help the learner solve problems innovatively.

Pilot Game Development Experiments

The development of our model and experimental environment is supported by initial empirical evidence gathered from the projects of undergraduate students performed at a college in the southeastern US (the College). In these projects, college professors of the School of Information Technology (IT), acting as subject matter experts (SMEs), engaged students enrolled in introductory programming and systems analysis classes in an active learning activity. This pilot project took place during the fall semester of 2013. The project lasted two months and was divided into five distinct phases: identification and description of the project, analysis and planning, development of software, testing the resulting product, and presentation for evaluation. The starting point was determined to be the automation of a flip book used by students in the pre-K program at a school in the southeastern US. The flip book is sent home daily with students, and parents are asked to spend ten minutes per day with their child practicing suggested learning activities. It was determined by the researchers of this study that the pilot program would be deemed successful and warrant additional study if introductory programing students could create software that emulated half the games in the flip book.

The initial tasks and platform constraints chosen for creating a program were set by the faculty member implementing the pilot study and included: counting the spots found on a pair of dice, adding two numbers that are less than ten, identifying the color of objects, identifying the shape of an object, spelling the words for colors, animals, and shapes, designing a user interface to select games, and creating games that combine two or more of the activities listed to increase complexity. In terms of equipment and hardware, it was determined that the program should successfully run using Windows XP Professional as the minimum standard for an operating system, and the computer hardware used to run the operating system should be at least a 1 GHz processor with 512MB of system memory, and 1 GB of available hard disk space.

The second phase of the pilot project entailed tasking a team composed of four students enrolled in an introductory systems analysis and design class with evaluating the feasibility of creating the proposed software, identifying risks and threats, and ultimately developing a plan to guide the creation of a prototype software application. The information and pseudo-code, obtained in phase 2, was then passed to a four member team of introductory programming students. This signaled the beginning of phase 3 by creating input-processing-output (IPO) diagrams from the pseudo-code and recommendations for the software that would be created to simulate the flip book. The students in the programming group immediately chose to elect a project leader who would be tasked with coordinating tasks, graphical and design elements, and reporting progress to the sponsoring faculty member. The other three members of the team chose an area of personal interest and begin developing the games. Software developed by one team member was evaluated by the faculty member overseeing the project and the other members of the team. In this fashion, a feedback loop was created to correct, improve, and evaluate as an iterative process.

Two weeks following the close of the fall semester, a faculty member from the School of Education, an educational unit within the College, presented the project idea and results to a principal, assistant superintendent, and technology officer for a county school system in the southeastern US. The central tenets presented to the representatives of the school system were: 1. College students did not intend to change the educational curriculum in place. The students would merely use technology to enhance the education already being transacted. This would attempt to implement technology in a cost-free fashion, support the home study approach of the flip book in the absence of parent availability to help the child, and create re-usable modules and frameworks for the classroom. 2. College students in the field of IT would not have contact with the actual elementary school students, but would use feedback from teachers for improvement, continued development, and ideas for new software. 3. All software would be given freely at no charge to all interested parties, including the school system, teachers, parents, and students with the condition that the recipients could not in turn sell or copyright the product. It is the intention of the researchers to adhere to open source policies. 4. A successful development of software will ultimately span platforms to cover various mobile devices, span fields of study to include science, mathematics, history, natural sciences, and others, and allow the software to remain consistent in appearance and function while it "grows" with the K-12 learner.

Given the limited amount of time possessed by K-12 teachers, interaction and feedback will have to be scheduled in a way that does not interrupt their day to day activities. Additionally, the software will need to be developed in conjunction with various SMEs as the project begins to cross grade levels and add subject matter of increasing complexity. Following the presentation and discussion of the project, it was determined that the initial relationship with the southeastern US county school system would be limited to a small student population spanning grades 2 – 5 in an effort to control quality and minimize the intrusive nature of collecting feedback from K-12 teachers.

Educational Game Laboratory Model

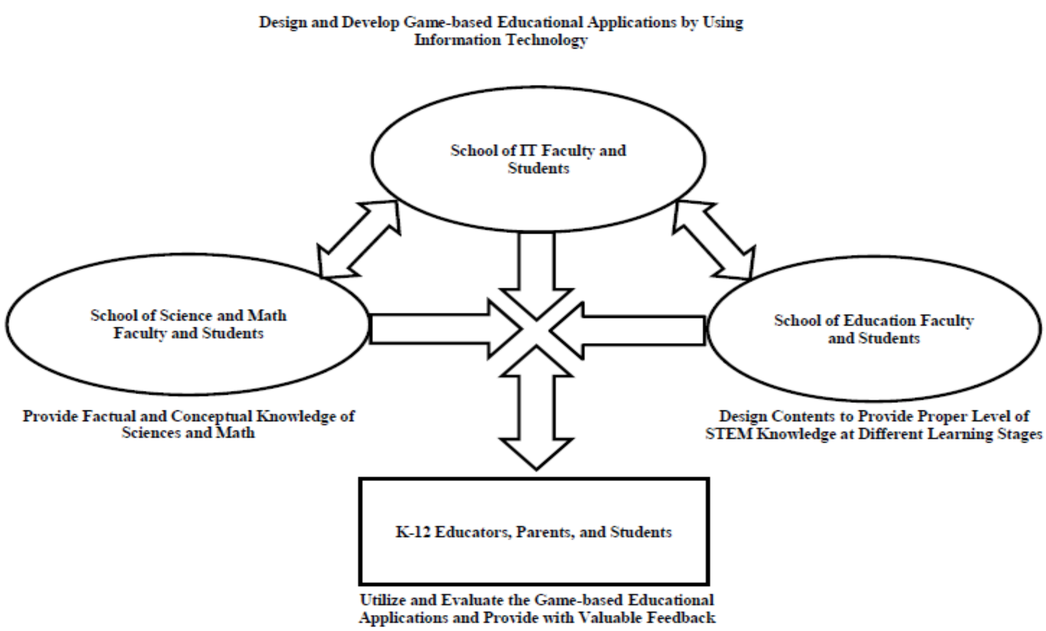
It is imperative to engage experts and stakeholders in the process of developing content-rich, stimulating, relevant and highly interactive game applications. Toward this end, an experimental design is put in place aiming to team up students from different schools at the College in the effort to develop a suite of applications targeting low-performing school children. In our model, faculty and students from the School of Information Technology will form a multimedia educational game laboratory to work together with faculty and students from the School of Science and Math and the School of Education, other educational units of the same college. Figure 1 depicts the proposed interactions among the members of this consortium.

Experiment

The School of IT offers a Bachelor of Science degree in Information Technology with a concentration area in Game Design and Development. Faculty and students of the School of IT will design and implement various multimedia, 2D/3D animations, and gaming features to make K-12 students immerse into the games and learn foundational STEM knowledge by the way of playing. For example, in the game applications designed to teach the factual and conceptual knowledge of the cell membrane, a detailed diagram of the cell membrane can be a game map, various substances such as molecules, ions, nutrients and so on can be created as game characters, and the actual behaviors of substances can be implemented by using the game rules. So students can be easily engaged in learning related terms of the cell membrane and how it functions by playing the game applications.

The School of Science and Math's faculty and students will provide the factual and conceptual knowledge about math and science curricula so proper and sound STEM knowledge can be implanted into the games. The School of Education will design the educational content to ensure that the adequate level of STEM knowledge would be provided at the different learning stages at K-12 institutions. The newly developed educational game applications would be adopted by K-12 educators to teach STEM knowledge to their students and these applications would be assessed by using evaluation schemes. In addition, students from the three aforementioned schools would play an important role in this model as they would come up with innovative ideas about effective gaming features for different age groups; design the learning processes; and develop 2D or 3D educational games. By participating in the project, students could obtain a more solid understanding of their own knowledge domains, improve their own problem solving skills, and have a chance to apply their respective knowledge bases to solving real-world problems.

Figure 1. Educational game laboratory model



Evaluation Methods

To ascertain the level of effectiveness of educational games under development, a number of rubrics and their indicators are currently being assessed. One of the approaches designed to evaluate the effectiveness of educational games is the RETAIN rubric, which is comprised of the indicators (relevance, embedding, transfer, adaptation, immersion and naturalization) that give the rubric its name (Gunter, Kenny & Vick, 2008). The rubric provides a weighing mechanism assigning the value from 1 to 6 to the aforementioned indicators. It also specifies three levels, which indicate the progression for each indicator from a less developed to a more developed state. The way the rubric was put to test stands out from other testing designs. The authors assembled a group of experts in the field of game design, who, along with graduate students, provided input necessary to conceptualize and test the RETAIN rubric. Math Blaster, a commercially successful educational game designed for K-12 systems, was evaluated for its instructional effectiveness. The results indicated that the game needed substantial improvement in a number of areas as well as the need to adjust the values assigned to the six indicators.

The literature focusing on evaluation of the effectiveness of instructional games addresses the solutions available for instruction both at a college (university) and K-12 levels. To provide some examples of the former focus, we will discuss the corresponding approaches used in deploying game applications in teaching physics and computer programming. Thus, Cataloglu (2006) utilized a computer simulation solution in undergraduate physics classes focusing on vector algebra. The author used pre- and post-test scores to evaluate the effectiveness of the educational software that provided several benefits for learners, including the ability to study the related topics outside of the classroom in groups. In a different study, Ljungkvist and Mozelius (2012) staged an experiment which exposed university students to entry-level programming concepts via educational game applications. In their experiment, the authors utilized semi-structured interviews which aimed to determine the level of satisfaction attributed to the educational value of game applications as well as to the use of technical features embedded in these games.

As a result, Ljungkvist and Mozelius (2012) unveiled a number of factors which boosted or lessened motivation on the part of learners. As for the level of satisfaction with technical features, the authors established that students found the drag and drop function overall useful. One insight that Ljungkvist and Mozelius (2012) received from the interviews concerned making a switch from the drag and drop function to code writing as a way to progress from a simple to a more challenging programming environment. Thus, the use of qualitative approach in staging experiments involving educational games helped researchers uncover insights related to the level of user satisfaction. While the retention of declarative knowledge was not measured, the collected feedback could potentially be used for improving the design of learning tools.

Next, we want to provide an illustration as of how the effectiveness of instructional game applications is evaluated in K-12 systems. Thus, Habgood and Ainsworth (2011) carried out an experiment attempting to test the benefits of Zombie Division, a game application, which aimed to teach mathematical concepts to elementary school children. The authors assessed the benefits gained through the learning experience relying on pre- and post-test scores and having the performance of three groups overall evaluated. All three groups were exposed to the game deployed in the study. The first group received instruction via interactive elements embedded in the game. Habgood and Ainsworth (2011) called this learning approach intrinsic. The second group was exposed to mathematical concepts by completing a multiple-choice quiz following the completion of a given challenge level. This approach was labeled extrinsic. Finally, while the control group played the game, students in this group received no mathematical instruction at all. As the result of the experiment, elementary school students in the intrinsic group demonstrated a higher level of understanding of the learned concepts compared to students in both control and extrinsic groups.

In sum, the use of a control group as well as pre- and post-test scores appear to be a prevalent approach for evaluating the effectiveness of instructional game applications. In a similar manner, our experiment will rely on a group of students exposed to the lessons involving gaming tools and a control group without such exposure. Pre- and post-test scores will be used to determine the effectiveness of proposed gaming software. At the same time, panels of experts and user interviews emerged as ways to enhance the value of game applications by going back to the design phase. Offering a stimulating environment capable of engaging low-performing school children in learning the STEM curriculum is the primary goal of the proposed experiment. Higher scores on post-usage tests would be an ultimate manifestation of the success of educational game applications.

Conclusion

Game-based learning, backed by the theoretical underpinnings of active-learning paradigm, presently seeks to establish a strong footing in K-12 systems. It is projected that educational game applications would become mainstream educational tools in the near future (Johnson et al., 2012). The model for the adoption of STEM-related educational games developed in this study embraces the input from a number of stakeholders aimed to customize the content and delivery methods for the K-12 school districts in the service area of the College. The stakeholders involved in the program dedicated to designing and developing customized educational games for the STEM curriculum include students and faculty from the School of IT, School of Education and School of Science and Math. In addition, K-12 teachers and administrators will play their role by identifying specific areas that need attention. This collaborative effort aims to create a learning environment which could potentially increase the interest and motivation on the part of K-12 learners to embrace the STEM curriculum. Ultimately, the impact of the proposed model would be evident via a positive change in the scores of related tests.

The study has developed the rationale for engaging different educational constituencies in a large-scale experiment by relying on initial empirical evidence gathered via pilot educational game development projects. A pilot program to evaluate student interest and obtain feedback was conducted during the fall semester of 2013. Following the close of the semester and successful creation of several education-based games, all students involved expressed interest and desire to continue and grow the project. Ideally, the K-12 student will follow a similar progression as the higher education student involved. Both sets of learners will first encounter the educational software as it employs simple concepts, but the sophistication and content of the software will develop along with the skill level of the practitioner.

We propose that, in a progressive fashion, student work cohorts or project teams will work with K-12 schools to develop software that supports the learning and mastering of skills in the various STEM areas. The integration of a consistent user interface and learning platform will remove the frustration encountered by students and teachers alike as education is transacted across progressive levels as a student advances through the curriculum. By using a game-based approach to education, the teacher is enabled to meet students on a comfortable playing field that allows education to be transacted through content, desirable outcomes, and game rules. To optimize the impact of the proposed model, we envision the early intervention of college-level constituencies in the effort to enhance the instructional effectiveness in the K-12 system. The School of IT would offer the expertise in the area of designing and developing software applications. Other educational units of the College would provide the factual and conceptual knowledge about math and sciences as well as proper delivery methods for different levels of STEM knowledge. Representatives from the School of IT, the School of Education and the School of Science and Math would serve on a panel of experts providing their viewpoints regarding the usefulness and effectiveness of various components of proposed gaming software solutions.

The performance of K-12 students participating in the experiment would be measured against the criteria set for the STEM curriculum. This includes a set of standardized tests. In addition, specific indicators focusing on qualitative aspects such as user satisfaction with technical features and ease of use will be developed. Finally, a rubric would be developed focusing on the indicators which could help designers come up with enhanced features and more effective modes of content delivery. All these mechanisms are designed to measure and advance the effectiveness of educational software. Obtained performance results as well as feedback from users and educational software experts would present an opportunity to do follow-up research. This research could potentially shed more light on the impact of gamification on learning activities in K-12 systems as well as make a contribution to the active learning literature. Given that game-based learning is an emerging and rapidly developing approach to education, our study would produce valuable evidence related to the effectiveness of a novel game development model involving stakeholders from both higher education and K-12 systems.

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Biographies

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Dr. Myungjae Kwak holds a Ph.D. degree in Information Systems and Technology and currently is assistant professor of Information Technology at Middle Georgia State College. He has broad experience in both academics and the industry. Dr. Kwak has published peer reviewed journal articles and conference papers over the years and has worked for more than 10 years in software development and gaming companies. He is currently teaching courses in programming and game development.

Dr. Kevin Floyd is program chair and associate professor of Information Technology in the School of Information Technology at Middle Georgia State College. He teaches in the areas of web development, web programming, and application development. His current research interests are in the areas of open source technologies, web accessibility, and student learning and engagement strategies.