AC 2009-658: A VIDEO GAME FOR ENHANCING LEARNING IN DIGITAL-SYSTEMS COURSES

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Dr. Butler-Purry has served on the TAMU Center for Teaching Excellence (CTE) Faculty Advisory Board, was a 2004-05 CTE Faculty Associate, is her department's ABET coordinator, and is an ABET Evaluator. Additionally she has received awards for outstanding teaching from TAMU ECE students and her college. Also as an African-American female, she is interested in the impact of teaching materials by gender and ethnicity.

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Dr. Vinod Srinivasan, Assistant Professor in the Department of Visualization, serves as a co-PI for the project. Dr. Srinivasan has been teaching game design for the past two years. He has a background in engineering and computer graphics and extensive experience in software design and development, particularly in the area of interactive computer graphics. His research interests include applications of visualization in education, simulation, and design, with particular emphasis on computer games and their use as tools for learning and teaching. He is currently working on an NSF-supported project to develop interactive software for Civil Engineering education. He is also working on several serious game projects including an NIH-supported SBIR project to develop game-based exercises for the design of assisted living facilities.

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Dr. Susan Pedersen, an Associate Professor of Educational Psychology, serves as Co-PI and assists with the development of the video games and the assessment and evaluation. Her research focuses on the design of innovative educational software to support student-directed learning, and she was the lead instructional designer of Alien Rescue, winner of the 2001 Learning Software Design Competition. Specifically she will provide expertise on the application of learning theory to the design of video games for teaching/learning and assessment of student learning.

Video Game for Enhancing Learning in Digital Systems Courses

Abstract

In today's world, video games have become an essential part of children's culture. The emergence of the "Gamer Generation" presents interesting challenges to educators. Traditional teaching methods and tools have clearly not had the same success as they had in the past. It has become apparent that our instructional methods and tools need to take into account the changing profile of students entering our schools and colleges. This paper reports on a National Science Foundation (NSF) Combined Curriculum and Laboratory Improvement (CCLI) project at Texas A&M University (TAMU) which entailed the development of a prototype implementation of a video game to demonstrate its potential and identify needs for revisions and future design prescription. The video game will be integrated with currently used instructional techniques in Digital Systems courses. The prototype was designed, developed, and tested on students enrolled in Digital Systems courses.

The prototype includes a 3D and a 2D environment. The 3D environment provides a game world in which the player, using a first person view, navigates through a series of obstacles. The 2D digital circuit design module provides learning exercises that teach sum-of-products logic design concepts with truth tables. A preliminary study of the 2D digital circuit design module was performed in December 2007. Both a usability study and a pilot test of the full prototype were performed in April 2008. The purpose of the studies was to get feedback from students on various features and graphics of the prototype and to evaluate the effectiveness of the prototype in teaching. The students were excited about the possibility of using a video game for learning in ECE courses.

Details about the prototype and the evaluation results from the study will be presented in this paper. The game will be further developed and evaluated over the next few years.

Introduction

In the Introduction to Digital Design (DD) course, offered at Texas A&M University and in most computer and electrical engineering programs, addresses several complex concepts that some students find difficult to grasp. For example, thinking in terms of binary numbers and variables, viewing design from a systematic approach, and sequential concepts/feedback systems are new or abstract concepts that some students are slow to grasp. The course readings and support lectures are selected to address these concepts; however, many of the students do not read the assigned materials because it is not their preferred approach for knowledge intake. The laboratory component of the course tries to introduce the students to course concepts from an experimental perspective to address students whose learning styles prefer a concrete teaching style. A considerable number of students also convey boredom or lack of challenge with the laboratory assignments.

As new pedagogy is considered for this course, it is clear that the instructional methods and tools need to take into account the changing profile of students entering our schools and colleges. A

direct consequence of the diminishing returns provided by existing instructional methods is the growing interest in the educational use of video/computer games¹. Prensky argues that “computer and video games provide one of the few structures ... that is capable of meeting many of the Gamer Generation’s changing learning needs and requirements”².

Although the emergence of the “Gamer Generation” is a recent phenomenon, the literature on educational use of games dates back to the early 1970s³⁻⁸. In the 1980s, researchers started studying computer and video games from a cognitive and educational point of view. Greenfield⁹, and Loftus and Loftus¹⁰ studied the role of learning and thinking in video games. Loftus and Loftus posit that games combine two ingredients – intrinsic motivation and computer-based interaction – that make them potentially “the most powerful educational tools ever invented”. More recently, Gee studied what positive things can be learned from video games and suggests that games involve intricate learning experiences that have a great deal to teach us about learning and literacy¹¹. Video games also teach deductive reasoning, memory strategies, and eye-hand coordination¹². More importantly they can provide a connection between abstract ideas and their applications in real world problem solving¹³. The rich virtual worlds in games can also provide multiple contexts for learners to understand complex concepts^{13, 14}.

The topic of game-based learning has also received attention because of concern that the science, technology, engineering and mathematics (STEM) needs of U.S. students are not being met¹⁵. The Federation of American Scientists (FAS), the Entertainment Software Association (ESA) and NSF organized a National Summit on Educational Games in October 2005 with the specific objective of discussing “ways to accelerate the development, commercialization, and deployment of new generation games for learning”¹⁶. Among the reasons they cite for why the United States should focus on digital games for learning, is the fact that video games “require players to master skills in demand by today’s employers – strategic and analytical thinking, problem solving, planning and execution, decision making, and adaptation to rapid change.” They also identified several attributes of video games that are important for learning: “clear goals, lessons that can be practiced until mastered, monitoring learner progress and adjusting instruction to learner level of mastery, closing the gap between what is learned and its use, motivation that encourages time on task, personalization of learning, and infinite patience.”

Although, there is a large body of evidence for the educational potential of games, adoption rates are still very low^{1, 17}. One reason for this is the lack of empirical evidence for effectiveness of games as learning environments¹⁷. The National Summit on Educational Games also identified the lack of data showing that learning games are effective as one of the roadblocks to bringing games and simulations to learning¹⁶.

This paper reports on a National Science Foundation (NSF) Combined Curriculum and Laboratory Improvement (CCLI) project at Texas A&M University (TAMU) which entailed the development of a prototype implementation of a video game to demonstrate its potential and identify needs for revisions and future design prescription. The video game will be integrated with currently used instructional techniques in Digital Systems courses. The prototype was designed, developed, and tested on students enrolled in a Digital System course and an Introduction to Engineering course. Details about the prototype and the evaluation results from the study will be presented in this paper.

Game Prototype

The prototype includes a 3D and a 2D environment. The 3D environment provides a game world in which the player, using a first person view, navigates through a series of obstacles. The 2D digital circuit design module provides learning exercises that teach concepts for sum-of-products logic design from truth table models.

The prototype version of the game starts with the player in one corner of an imaginary 3D world similar to those found in first person-shooter games. The player's goal is to reach the exit, which can be accomplished by unlocking several doors and obtaining two skill upgrades. At each locked door, the player is presented with a sum-of-products combinational circuit design problem. Successfully designing a circuit that satisfies the problem unlocks a door. Skill upgrades are obtained in a similar fashion. A static overview map provides the player with information about where s/he is in the 3D world and where the doors, upgrades and exit are located. Figures 1 and 2 show screenshots of the 3D environment.

The game switches to a 2D environment for the digital circuit design problems. The problems are presented in the form of a truth table specifying the desired output for the given inputs using problem based learning¹⁸. The students are taught sum of products design concepts through an initial problem (with one external output) with one truth table row with a value of '1' and the remaining rows with a value of '0'. This problem yields a circuit with one AND gate. Next a problem that has two rows with a value of '1' and the remaining rows with a value of '0'. This problem yields a circuit with two AND gates and one OR gate. Then a series of problems are introduced with increasing complexity and multiple external outputs. The goal is for the students to learn the procedure for designing sum of products circuits from truth table models.

Figure 1. Screenshot of the 3D environment as a player approaches a locked door

Figure 2. Screenshot of the 3D environment as a player approaches a locked and an unlocked door

The player can drag and drop various gates from an inventory box onto a board which has m number of external inputs and n number of external outputs. Wire connections between the gates, and external inputs and outputs can be made using mouse clicks. The player can toggle the input states between logic '0' and '1'. The game updates the external outputs automatically to indicate the values of the outputs of the current circuit for the specified input values. The wires are also colored to indicate the logic '1' or '0' states at the wire inputs. These features allow the player to follow the circuit from inputs to outputs observing what happens for each input combination, providing a circuit debug option. When the player has completed a circuit, s/he clicks a button that invokes a Boolean Algebra-based solver in the prototype which determines if the circuit is equivalent to the truth table. The game visually indicates how many of the truth table combinations the circuit satisfies. If all combinations are satisfied, the player has successfully solved the problem. Otherwise the player may redesign the circuit. Figure 3 shows a screenshot of the 2D environment. The exercises in the prototype version range from simple single gate problems to more complex sum-of-products combinational circuit problems with multiple inputs and outputs, with the complexity increasing as the player advances in the 3D world. The game prototype was developed in C# using the Microsoft XNA framework. Development and testing was done on PCs.

Figure 3. Screenshot of the 2D digital circuit design environment

Evaluation Approach

A preliminary study of the 2D digital circuit design module of the prototype was performed in December 2007 with volunteer students who were enrolled in an Introduction to Digital Design course that semester. Both a usability study and a pilot test of the prototype were performed in April 2008 with volunteer freshman students who were enrolled in an Introduction to Engineering course at the time of the study or the previous semester, and a few upper level ECE students who were interested in providing feedback on the video game prototype.

Thirteen (13) students, who are members of the target audience of the video game prototype, participated in the preliminary study that included a survey and interviews. The purpose of the study was to get user feedback on the 2-D design module and student opinions on using video games for learning. Almost 80% of the participants in the preliminary study had been playing video game for ten or more years. Eleven of the students were favorable to learning course material through video games. Also more than 60% of the students stated that they would prefer doing problems in this manner to doing them on paper.

The usability study of the prototype was conducted with four undergraduate and graduate students approximately three weeks before the pilot test, and revisions to the program based on some of the results of the usability test were made prior to the pilot test. The pilot test of the prototype was administered to 13 participants, 9 of whom were members of the target audience for this video game prototype. Students logged into the video game and were allowed to play for up to 75 minutes. Two instruments were used for data collection: a participant survey and a conceptual test. The participant survey consisted of 28 items: 8 items dealt with demographic information, 14 were Likert-style items with four responses ranging from Strongly Agree to Strongly Disagree and addressed opinions about the game, and 6 were open-ended questions.

The conceptual test consisted of two items that asked students to solve problems, about design of two-level sum of products combinational circuits using truth tables, which were similar to the ones presented in the game. The conceptual test was delivered both before and after students played the game.

Participants' reaction to the game was generally positive. All students appeared to be genuinely engaged in the game during the pilot test. Several students continued to play the game well beyond the allocated time in an effort to reach the exit and complete the game. We also observed that students were more methodical in their approach to solving the later-stage problems, while they used more of a trial-and-error approach to the early stage problems. This seems to indicate that students did learn something about the process of solving the circuit design problems, although an analysis of their performance on the posttest does not necessarily demonstrate this learning.

Evaluation Results

Responses to items on the participant survey suggest that participants prefer to work on solving problems within the context of the video game to solving them on paper and that practice through a video game is more motivating than other methods of practice. The students liked many aspects of the gaming environment including the sense of achievement derived from making progress in the game, the opportunity to check the correctness of their answers, and the overall challenge and fun of the game. Though altogether students were quite positive about the game, they did offer some suggestions for improvements to its premise and format.

The pretest and posttest were completed by the nine students who were members of the target audience. Eight of the nine students received a score of 0 on the pretest; one student received a perfect score, indicating that this student was already proficient in solving the types of problems addressed in the game. Of the remaining eight students, four students improved their scores on the posttest, while four students again received a score of 0. The difference between pretest scores (mean = 0.22 out of 2.00) and posttest scores (mean = 0.72 out of 2.00) suggests that at least some of the participants in the pilot study did improve their understanding of combinational circuit design by playing the video game. Given the brevity of the game, this rise in scores is promising. While this increase may seem small, we should note that these participants were freshman who had been exposed to digital logic material in an Introduction to Engineering course for only 1.5 weeks previously and that exposure had been more than a month or a semester before. This exposure included digital circuit analysis concepts but not digital design concepts for simple sum-of-product circuits. For the four students who were able to comprehend the concepts that the prototype was teaching without learning hints, they learned how to design the sum of products combinational circuits. However the four students who could not comprehend the concepts without learning hints were unable to learn the design concepts.

Conclusions and Future Work

The feedback from the prototype project indicates that the use of a game in the course could lead to positive results in terms of student engagement and learning. Students were also comfortable with the format of the game (navigating in the 3D environment and switching to a 2D screen for

the digital circuit problems), although a few students did have some early-stage difficulties with navigating the 3D world in first-person view. Students also pointed out that the game needed a meaningful meta-narrative beyond simply navigating the 3D world to find the exit. Overall the results of the pilot project are encouraging and tend to support the findings of other researchers in the field. However, more evaluation with a larger sample size is needed to obtain more conclusive results. The prototype was also shown to high school seniors and their parents during an ECE department recruitment program in April, 2008. The students were excited about the possibility of using a video game for learning in electrical and computer engineering courses.

A full video game is currently being designed for further evaluation and more comprehensive testing. The proposed video game will build on the existing prototype, adding several new user interface enhancements and modifying some of the current features. A story-line that ties the problem solving to a larger goal will be added. The number and variety of problems presented to the player will also be expanded. A video tutorial on how to play the game and solve problems will also be developed. Another important addition will be a context-sensitive help system that provides hints and assistance when players are stuck in a problem. The game will also include an in-game, player-controlled information resource that explains key concepts that the game is intended to address.

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