Impact of Engineering Design Serious Game on Student Learning in a K-12 Curriculum

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Abstract

There is a call to significantly enhance the learning and teaching of science, technology, engineering and mathematics (STEM) by K-12 students and teachers, through research and development of innovative resources, models and tools[1]. There is also a need to infuse engineering content and design principles for student learning into diverse K-12 technology education[2, 3]. Nolan Bushnell, Founder of Atari, father of the video game industry says, "If we can integrate games within learning across the curriculum we can make education the proper competition for our children's minds." BBC factual entertainment states that "People learn through games. Ninety-nine percent of boys and 97% of girls aged between 12-17 play video games." In a survey conducted in the United States with 25,544 teachers, 65% of teachers were interested in the use of games in the classroom[4].

Serious games can be used for education at all levels, from preschool and elementary school, through middle school and high school, into higher education, and even into the job market. This paper discusses the implementation of the engineering design game to a group of senior level high school students. The main objective of the game is to teach the engineering design process to the students in a fun gaming environment. The game has different levels (tutorial, water tower level & train bridge level) and progressions, and uses a tower building simulation as an example to explain the design process and to assess their understanding of the game. The goals (for example: achieve a minimum height, do not exceed a maximum cost, and bear a minimum load) of the game are clearly defined at the beginning of each level. After learning the engineering design process through the game, the students work on a hands-on design project applying the design process. The effectiveness of the game is examined through a convergent parallel mixed methods approach[5]. The quantitative data will be studied using an expanded 3P model[6], called the 4P model (presage, pedagogy, process, and product). This model provides a theoretical framework for the evaluation questions that guide the qualitative study. The questions focus on students' perceptions of the value and nature of game and the effectiveness of the game in achieving student-learning outcomes. A team of external researchers collected the qualitative data from students through a survey and focus group. Analysis of the data from both a quantitative and qualitative perspective is expected to provide a set of findings. The results of this project can contribute to understanding whether games facilitate students' deep learning about the concept of design process.

Introduction

The problem of student motivation persists even today in the K-12 level of education and is a factor in issues such as student underachievement and retention[7]. Students have made real academic strides in most states, but no state is on track to getting all students the STEM skills they need to succeed in college and career. Low-income and minority students lag farthest behind. Over the past decade, almost $3 billion has been invested in educational technology. In 2012, more than $1 billion was raised for educational technology to improve student motivation and learning processes[8]. With the investment in technology and the need for new instructional techniques to improve student motivation, we investigate new innovative instructional materials like serious games and check their effectiveness at the K-12 level to infuse interest in the students to pursue STEM majors.

"To teach is to engage students in learning[9]." Researchers agree that students need to be engaged in learning throughout their professional lives in order to perform effectively in an unknown real-world future and instructors must tailor their courses with that in mind[10, 11]. There is also a need for instructors to try out innovative instructional methodologies or techniques in their courses to achieve specific student learning outcomes. Falkenberg[12] stressed the need for new instructional pedagogies to be developed in order to utilize information technology more effectively in classrooms. The greater the level of student involvement or engagement in academic work or academic experience in school, the greater his or her level of knowledge acquisition and general cognitive development[13]. Both researchers stress the need for new studies on innovative learning practices and instructional methodologies to identify their impact on students' learning and to determine whether they could help address issues like student engagement and retention.

Serious games are games, or game-like interactive systems, developed with game technology and design principles for a primary purpose other than pure entertainment. As Prensky[14] pointed out, games are good for two things. First, there are particular techniques or attributes of games that can help students learn complex material faster, and understand that material better. Second, games can increase the level of engagement of the students/trainees so that they want to play the game and learn how to successfully complete the game. There is an abundance of literature which shows that serious games contain the pedagogical elements to enhance student learning and skills[15-19]. Initial studies have shown that serious game teaching effectiveness is 30% more than the classic lecture method of teaching[20]. Serious games have been proven to improve student motivation, engagement and achieve specific learning outcomes while teaching engineering concepts[21-24]. In the following sections, the engineering design serious game will be briefly explained. The later sections will cover the implementation, evaluation, findings and limitations of this study.

John Gill, physics teacher at Lee Scott Academy School, was planning to implement a trebuchet project with his students in a physics class. He wanted to introduce the design process in the class before starting to design the trebuchet. The engineering design serious game was chosen to introduce the design process to the students. The engineering design serious game will be referred to as a “game” in the following sections.

Engineering Design Game

The game was designed to teach the engineering design process to the students. The engineering design process is inspired from the Pahl and Beitz[25] model of the design process. The game is titled 'Engineering Heights: The Design Process in Action'. Some screen shots of the game are shown in Figure 1.

Figure 1. Screen shots from the design game

Figure 2 shows a basic block diagram of the game user flow experience. We will briefly discuss each block of the user flow experience.

Overview

This section of the game defines the goal of the game, which is to teach the engineering design process. It also brings out the need for the design process by presenting examples of failed bridges. In the overview, the students are introduced to basic construction materials like beams and joints required to build their structure.

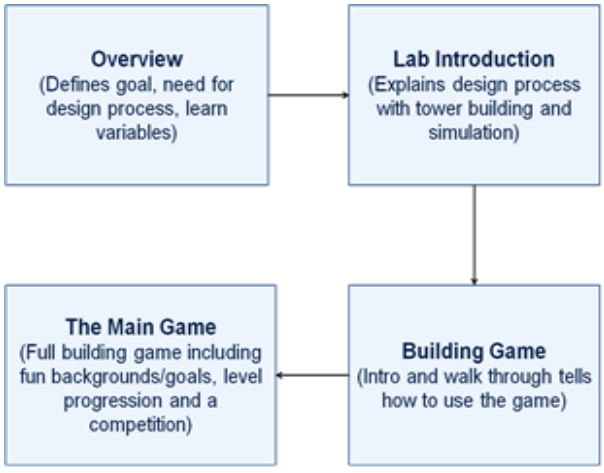


Figure 2. Game user flow experience

Lab Introduction

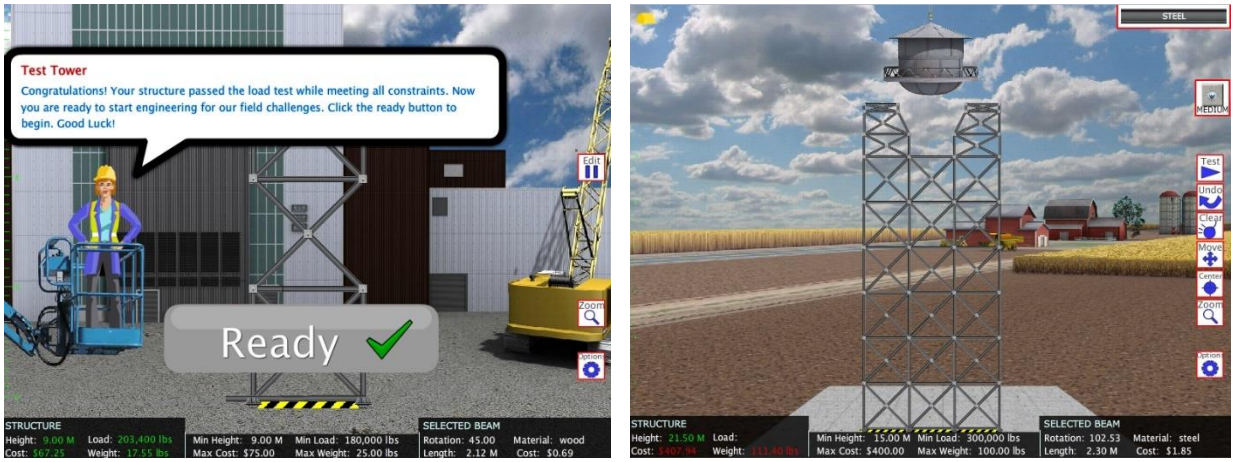
In this section, the students review in detail each of the core engineering design process steps. Once they learn these steps, the student will have a chance to design a structure and make decisions that affect the weight, cost and the load capacity of their structure. This is done by selecting pre-defined shape structures and different material, beam and joint choices. The game simulates their tower and shows the estimated load that their structure can withstand.

The Building Game

In this part of the game the students are guided on how to use the tools and screen areas to design build and test a structure from scratch. It is like a tutorial where they have to join the dots and learn how to build their structure and use the tools to test their structure. Several tool tips are used to convey the message to the students. We have different goals for the students in this building game level. A screen shot of the building game level is shown in Figure 3.

The Main Game

The main game consists of three levels. The first level is a simple test tower where the students are given some constraints on weight, cost, and load to build their tower. The second level is a water tower level where they have to build a tower to hold the water tank at the top of their tower. The third level is a train bridge level where the students have to build a structure to support a train bridge. The difficulty of the level increases as the students' progress through different levels. The game also allots a score for each finished level as a measure of students' performance. A screen shot of the water tower level is shown in Figure 3.



Building game level *Water Tower Level*

Figure 3. Screenshot of the building game and the main game

Implementation

The game was implemented at Lee Scott Academy, a private school in Auburn, Alabama at the senior level. The research study took place during the fall of 2013. The students had to go through an engineering design learning module which included a lecture on the engineering design process, and a design simulation game titled "Engineering Heights: The Design Process in Action." The responses were collected from 21 students in a physics class. The demographics of the data resulted in 12 males and 9 females. All the students were Caucasians and were 17-18 years of age.

Evaluation

In order to know whether the game is effective or not, it should be evaluated in the right manner. A common criticism of using new methodologies for teaching is that their effectiveness is never measured[26, 27]. The effectiveness of the game was studied using a Presage-Pedagogy-Process-Product (4P) model. It proposes that the presage conditions, along with games (pedagogy factor), combine to create the approach a student takes in their learning (process factors), which in turn influences the improvement in achieving outcomes (product factors). Figure 3 shows the 4P model with games being the moderating variable. Since this is an experimental study, we used the process and the product variables from the 4P model to test the effectiveness of the game among the students. The next stage of this research study will use a control/experimental setting and use the full 4P model to check the effectiveness.

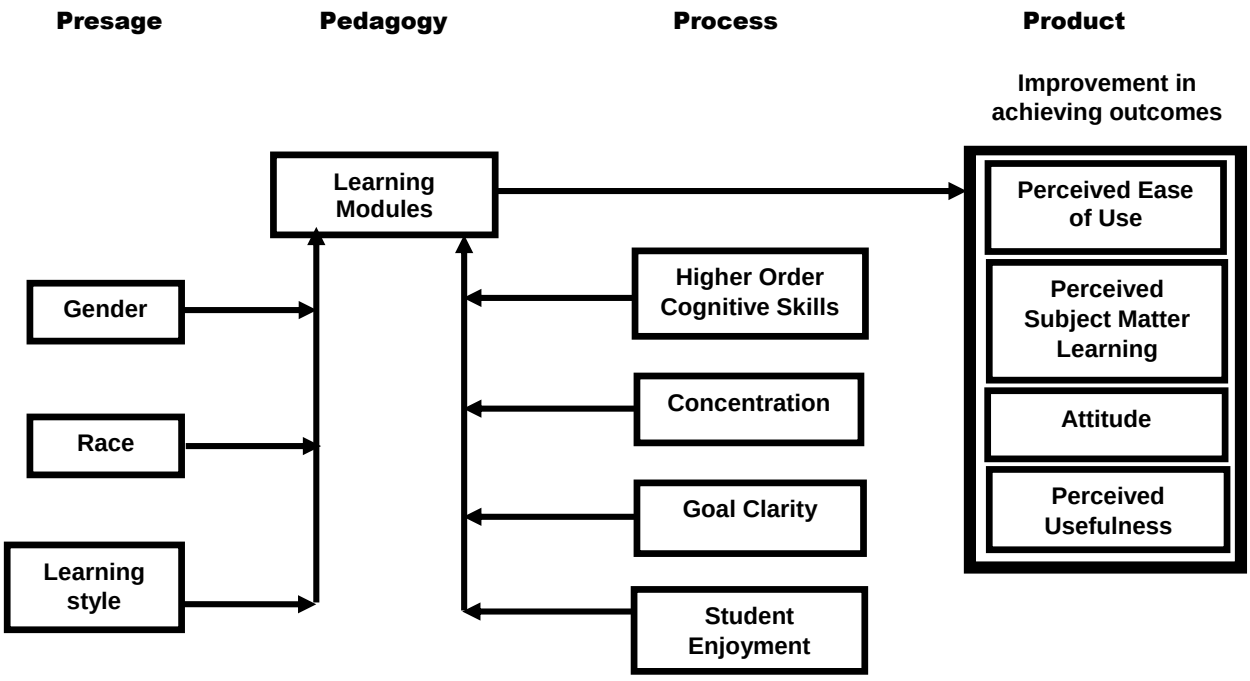


Figure 3. 4P model with games as the moderating variable

Presage: Presage factors are factors that exist prior to the engagement and that affect the learning process. The presage factors considered in this model are gender, race and learning

style. These factors interact with the game to affect the process and the learning outcomes. The presage factors usually constitute the independent variables in the 4P model.
Pedagogy: Different games can be used for both control and experimental sections. We have only one experimental section for this research study.
Process: The heart of the teaching/learning system is at the process level, where the learning-related activity produces or does not produce the desired outcomes[28]. Process incorporates the students' learning experience. The four process variables used in this model are higher order cognitive skills, concentration, goal clarity and student enjoyment.
Product: Product is the outcome of learning. Product factors are indicators of knowledge, skills and behaviors students gained by participating in the learning process. We have identified four product factors in the research model.

Data Analysis & Results

Data was collected using multiple sources. An evaluation questionnaire was used to collect responses from the students. The questions used to measure the constructs in the model are available in Appendix A. The questions asked students to rate the extent of their agreement on the constructs (on a 5-point Likert scale) mentioned above in the 4P model. Table 1 shows the descriptive statistics of the process and the product variables. The findings indicate that the means of all the product and process variables are significantly higher than the neutral rating of 3.0. This might suggest that the game provided good concentration and goal clarity. The results also suggest that the students perceived the game to be useful and easy to use. The results in the table suggest that the students enjoyed the game and they perceive the game to be helpful in learning and improving higher order cognitive skills. These results are supported by student comments during the focus group session.

Table 1. Means and standard deviations of the variables

Variables	Mean	Std. Deviation
Concentration	3.99	.72
Perceived Usefulness	3.31	.63
Goal Clarity	3.99	.76
Perceived Subject Matter Learning	3.75	.59
Higher Order Cognitive Skills	3.65	.65
Perceived Ease of Use	3.65	.81
Student Enjoyment	3.60	.83
Attitude Towards Subject Matter	3.67	.57

Scale: 1 –Strongly disagree; 3 – Neither agree nor disagree; 5 – Strongly agree

A correlational analysis was performed to look at significant relationships between the product and the process variables and the results of the analysis are shown in Table 2. The results indicated a statistically significant relationship between majority of the process and product variables.

Table 2. Results of correlational analysis between product and process variables

Product / Process	Perceived Subject Matter Learning	Attitude	Perceived Ease of Use	Perceived Usefulness
Higher Order Cognitive Skills	r = 0.882 p = .000	r = 0.849 p = .000	r = 0.728 p = .000	r = 0.536 p = .012
Student Enjoyment	r = 0.789 p = .000	r = 0.827 p = .000	r = 0.642 p = .002	r = 0.661 p = .001
Goal Clarity	r = 0.658 p = .001	r = 0.471 p = .031	r = 0.518 p = .016	r = 0.279 p = .220
Concentration	r = 0.453 p = .039	r = 0.579 p = .006	r = 0.346 p = .131	r = 0.412 p = .063

r- Pearson correlation coefficient.

*High values of r (>0.50) indicate strong relationship between two variables[29]

Students learned about the engineering design process from the game. Comments from students collected at a focus group session indicated that the game helped in understanding the engineering design process through a real-world tower building example. The student group which is involved in the robotics team at the school said "We did not have a design process in building our robot and we get a score when we report our process through our Project Engineering Notebook. The game really helped in improving our knowledge about the design process and in getting a higher score on the Project Engineering Notebook." Another student said "I like the game because you get to try different shapes and test it. This is not possible in the real-world." The students also said that they would like to learn more concepts through a fun, engaging and gaming environment. Student comments also showed that individuals were provided a challenging, compelling learning experience through playing the game. Students also indicated that the game was fun, enjoyable and, for many, preferable to learning compared to other methods.

Summary and Findings

Based on the feedback of the students, the students liked the learning experience from playing the game. The use of games in a classroom is one way to engage and motivate students. In this study, we observed that all the mean ratings for the constructs were favorable (above the neutral rating 3.0) to the gaming environment. During the focus group sessions, the external evaluators also observed that goal clarity, concentration and student enjoyment are some of the key elements to achieve better learning effectiveness in a game learning environment. In summary, all of the significant findings in this study revealed greater gains in student perceptions who

participated in the research study, which shows that a game is a good instructional tool to teach engineering concepts to K-12 students.

Limitations and Future work

There are some limitations with the current research study. First, the study conducted is not done in a control/experimental setting to see the differences between the traditional learning environment and a game learning environment. This limitation is being addressed in the next phase of this research study. Second, the product variable measures of learning outcomes in this study are all based on students' perception (e.g., perceived ease of use toward learning environment). Any objective measures of performance (pre and post-test or a hands-on exercise) to test the students understanding of the design process would be a good addition to the study. Third, a longitudinal study implementing games in a curriculum would reveal some interesting results about the feasibility of games being a supplement to traditional lecture methodologies.

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Appendix A

Constructs/ Items	Measures
1. Higher order cognitive skills	• *The instructional materials in the engineering design game helped me identify engineering tools that will assist me in decision-making.* • *In this engineering design game I learned how to inter-relate important topics and ideas using the instructional materials.* • *In this engineering design game I learned how to identify various alternatives/solutions to a problem using the instructional materials* • *The instructional materials in this engineering design game improved my problem solving skills* • *I learned how to sort relevant from irrelevant facts using the instructional materials in this engineering design game.*
2. Concentration	• *I was absorbed intensely in the engineering design game.* • *My attention was focused on the engineering design game.* • *I concentrated fully on the engineering design game* • *I was deeply engrossed in the engineering design game*
3. Goal Clarity	• *I knew clearly what I wanted to do in the engineering design game.* • *I had a strong sense of what I wanted to do in the engineering design game.* • *I know what I wanted to achieve in the engineering design game.* • *My goals were clearly defined in the engineering design game.*
4. Student Enjoyment	• *The game has been enjoyable* • *This was one of my favorite games* • *I had fun working on this game* • *I enjoyed many aspects of this game*
5. Perceived Subject Matter Learning	• *I became more interested in the concept of engineering design process* • *I gained a good understanding of the concept of engineering design process* • *I learned to identify central ideas in the area of engineering design process* • *I developed the ability to communicate clearly about the concept of engineering design process* • *I was stimulated to do additional work in the area of "engineering design process* • *I found the engineering design game to be a good learning experience*

6. Attitude	• *From my experience in this engineering design game I believe engineering is irrelevant to my life* • *This engineering design game has increased my appreciation for engineering.* • *From the engineering design game experience I think engineering is highly technical.* • *This engineering design game has shown me that I can learn Engineering.* • *Engineering skills learned in this engineering design game will make me more employable.* • *The engineering design game was integrated in a way that made it easier to learn new engineering concepts.* • *The engineering design game emotionally engaged me in learning the topics.*
7. Perceived Usefulness	• *Using the engineering design game improved my performance* • *Using the engineering design game enabled me to accomplish my tasks more quickly* • *I found the engineering design game useful* • *Using the engineering design game increased my productivity* • *Using the engineering design game enhanced my effectiveness* *Using the engineering design module made it easier to do my work*
8. Perceived Ease of Use	• *Learning to use the engineering design game for performance-based activities is easy for me* • *I find the engineering design game flexible to interact in performing school-related tasks and activities* • *I find it easy to get the engineering design game to do what I want to do in performing school- related activities* • *It is easy for me to become skillful at using the engineering design game in school-related activities* • *I find the engineering design game easy to use at school* • *My interaction with the engineering design game at school is clear and understandable*