Assessing the Impact of Video Game Based Design Projects in a First Year Engineering Design Course

Joseph Ranalli* and Jackie Ritzko
Penn State Hazleton
Hazleton, PA 18707
*Corresponding Author: jar339@psu.edu

***Abstract*—Introductory engineering design courses are an opportunity to engage and encourage first-year engineering students. In one such course, we implemented a novel student design project using a commercial video game. The game, Kerbal Space Program, is a simulation of rocket travel and provides a reasonably realistic representation of rocket propulsion and orbital mechanics. Teams of students were tasked with designing a rocket that could fly to the home planet's moon and return safely. The efficacy of the project was assessed using a pre- and post-activity survey, and results are compared with those from a larger-focus research project on the effectiveness of toys in the classroom.**

Keywords—games; engineering design; engagement

I. INTRODUCTION

Engineering students' first experience with the engineering discipline often occurs within introductory engineering design courses. As a result, these courses play an important role in retention and engagement of students in engineering. A variety of strategies have been employed in the past to improve retention and engagement of students. This article details a preliminary study conducted as part of a larger programmatic investigation on the efficacy of toy-based engineering design projects to increase retention of students in engineering disciplines. The contribution we made was to investigate the potential of video games as toys within this context.

Student retention is believed in part to be related to student attitudes about engineering, confidence in engineering skills, and interaction with peers [1,2]. Our approach uses team-based, hands-on projects to engage students. Another aspect of our approach is to use projects that provide students with engineering related coursework that does not have the heavy math and science focus common to the majority of their first-year curriculum. This allows them to build confidence in engineering apart from their still-developing quantitative analysis skills. The impact of these strategies was assessed by pre- and post-activity survey on self-efficacy of learning in engineering, engineering career interest and student perception of program usefulness.

II. BACKGROUND

Video games are a ubiquitous form of entertainment in modern society. They can be now found on a variety of platforms including home computers, standalone gaming consoles and smartphones. The level of computational power used by these systems has grown substantially over recent years, to the point that video games may now contain sophisticated simulation environments for a variety of different types of physics. The combination of popularity and wide availability of these games has created a situation in which over 65% of college students report at least occasional video game use [3]. By leveraging the advanced computational platforms available for video games, there is an opportunity to engage students and harness an existing student leisure activity for educational purposes. A common aspect of many games is the development of a community of practice. As players collaborate, learning as a social process builds connections to what is being learned and situations where the learning can be applied [4].

Games and game-like activities have been used in a variety of classroom settings [5]. Educators have considered games as an environment for content delivery, where learning objectives are integrated with the game itself. Games may also be used as a practice environment for drilling and repetition in a (theoretically) more enjoyable task. Consideration has been given to "gamification," where common game reward structures are integrated into traditional learning to provide motivation. Lastly, games can be considered simply as a reward activity for students.

Previous studies have considered the ability of video games and other virtual environments to be used for engagement or learning purposes in an educational setting. In a physics classroom, virtual manipulative tools were shown to be effective as compared to hands-on experimental activity by students [6]. Coller and Shernoff [7] utilized games and game programming as an avenue to address numerical methods in an engineering simulation environment. They showed higher levels of student intrinsic motivation and overall engagement when working within the context of the game, as compared to traditional classroom activities. Other studies have considered the impact of mobile, augmented reality games in pre-college educational environments [8]. A study by Virvou et al showed gains in student learning through gaming especially in students whose previous mastery of the material was low, but caution

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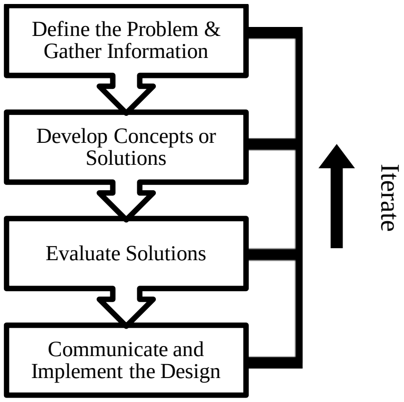

Fig. 1. The four-step engineering design model used in the course

that students will compare the production value in the games being used in the classroom with those commercial games that they encounter [9].

In this study, we considered the effectiveness of a commercial spaceflight simulation video game in the engineering design classroom. The game was used as an environment where students could practice engineering design by using the simulation to facilitate the production and testing of concepts throughout the design process. The game also produced a somewhat realistic depiction of the physics of rocket propulsion and spaceflight, providing students an environment to explore these concepts as they played.

III. DESCRIPTION OF THE WORK

This study was part of the Toys ‘n MORE research program, which focused on measuring student engagement and retention through a series of toy based interventions in introductory engineering design and other courses. This program spanned several sections of the course, as well as several different university campuses. The interventions were implemented individually by each instructor, resulting in some variability in the projects for each course, though with the common theme of using toys in some way. One example of the Toys ‘n MORE program using LEGO Mindstorms robot design was reported by Sholtz and McFall [10].

The course in question was Introduction to Engineering Design, a course intended for first-year engineering students. The course covers topics of “engineering design processes, methods, and decision making using team design projects,” as well as engineering communication and graphics. The formalized design process used as a guide for students was a four-step model, shown visually in Fig. 1. In this course, students worked in groups to complete two team design projects. Survey data was compared for two groups: all students completing the Toys ‘n MORE version of the course (909 students from 2009-2012) and three course sections of students who completed a project using the video game simulation (58 students during the 2012/2013 school year).

A. The Video Game Project

The project we implemented to investigate student response to video games in the classroom was based around a commercial video game entitled Kerbal Space Program [11].

Fig. 2. Sample screenshot of a rocket under construction

Fig. 3. Sample screenshot of a rocket in-flight

This game is still under development, but at present is sufficiently complete to provide a comprehensive spaceflight experience. In the game, players can construct rockets from a variety of parts. Some examples are solid rocket motors, liquid rocket engines and fuel tanks, guidance systems, fins and other steering components, radial and axial staging separators, landing parachutes and structural supports. After constructing a rocket, the game provides a simulation environment where these designs can be launched and flown (requiring manual piloting) into orbit in a virtual outer space that includes other planetary bodies. A pair of screenshots from the game is shown in Fig. 2 and Fig. 3. For our study, the demonstration version of the game was used, because it was freely available and used a smaller set of components. While still allowing students the freedom to explore in their designs, this limitation did help provide focus.

The project assigned to students was to investigate the rocket parts and develop a rocket that would be able to reach space, fly into lunar orbit and return to safely land on earth. This flight plan mimicked the real-life flight of Apollo 8. Note that the earth, moon and sun were the only astronomical bodies that could be visited in the demonstration version. Landing on the moon was provided as an optional extra-credit goal, due to the additional piloting challenges that we felt would turn the learning focus away from the design. Besides practicing engineering design within the simulation, students did need to develop insight into some basic orbital mechanics principles, like the relationships between velocity and altitude. The latest versions of the game include built-in tutorials that could also be used to help acclimate students to the simulation. Students were given some instruction on these topics, specifically on how to create an orbital trajectory that would approach the moon.

Two specific learning objectives were addressed by this project. First, students were expected to be able to apply a four-step engineering design process to successfully complete a design goal. The second learning objective was for students to be able to demonstrate effective and professional teamwork behaviors throughout the process. The design process-related outcome included identification and articulation of design problems and challenges, identification of specifications for the design, and development and testing of multiple concepts in reaching a final design.

The video game we used fit well with the design learning objective, in that it required a workflow where students would piece together components and conduct test flights to evaluate the performance. Within the game’s simulation environment, students encountered a broad set of challenges that their designs had to be modified to address. Example design decisions that students had to make were decisions about the type of rocket engine to use, the amount of fuel to carry, the rocket staging arrangement. In test flights students were able to observe how their choices impacted thrust-to-weight ratio, ease of control and flight stability, and how these parameters affected their ability to achieve their design goal. The application of the design process became a natural part of the playful activity. Another strength of this approach was the opportunity for students to iterate very rapidly on their designs.

The student deliverable for the project was a written report. They were instructed to focus on reflections about the implementation of the design process (e.g. concept generation and testing) and the measurable performance of their design. They were also asked to discuss their approach to teamwork in developing their design. Student grades were based primarily upon the stated learning objectives; their articulation of their design within the context of the engineering design process and their use of teamwork were the primary criteria. After completing the project, students received a detailed rubric providing the basis for their grade with an emphasis on the learning objectives. This was done to enable them to identify the shortcomings and receive feedback to improve their application of the design process on subsequent projects in the course.

B. Survey Data Collection

Student response to the learning activities was assessed using a survey adapted from the Longitudinal Assessment of Engineering Self Efficacy (LAESE) instrument [12,13] and a second technology self-efficacy instrument [14]. The pre- and post-activity survey was implemented for the entire Toys ‘n MORE program. The survey was made up of seven demographic questions and 41 items related to aspects of engineering self-efficacy that mapped into nine subscales:

- Teaming self-efficacy (3 items)
- Technology self-efficacy (3 items)
- Communication self-efficacy (4 items)
- Engineering self-efficacy I (5 items)
- Engineering career expectations (7 items)
- Engineering self-efficacy II (6 items)
- Feeling of inclusion (4 items)
- Efficacy in coping with difficulties (6 items)
- Math outcomes efficacy (3 items)

TABLE I. SAMPLE QUESTIONS FROM SELECTED SUBSCALES

Subscale	**Sample Questions**
	Prompt: How confident are you in your current skill and ability to… ***(Not at all confident = 0 to Completely confident = 10)***
Tech. self-efficacy	…design and build something new that performs very close to your design specifications? …quickly grasp the limits of a technology well enough to judge whether a project should use it?
Comm. self-efficacy	…organize a message so that it is clear and logical? …write reports that communicate clearly to the intended audience?
	Prompt: For each statement, indicate your level of agreement. (Strongly Disagree=0 to Strongly Agree=6)
Engr. self-efficacy I	-I can succeed in an engineering curriculum while not having to give up participation in my outside interests. -I will succeed (earn an A or B) in my physics courses.

Sample questions from three of the subscales are shown in Table 1. Note that the subscales detailed in Table 1 are those that had statistically significant results.

The pre-surveys were administered on the first day of class. This was to accommodate the fact that students were introduced to the game as a free-time activity at the beginning of the course so that they could play with the game freely and get a context for the upcoming project. The project was discussed with students at that time, but the formal assignment and expectations were provided in the 4th week of the course. Students had four more weeks to work on their designs and reports. The post-surveys were administered in the 8th week, after the projects had been completed.

IV. RESULTS AND DISCUSSION

Results are considered for two separate groups of students. The first group represents students taking a Toys ‘n MORE version of this course at our campus that did not include the video game. This group was made up of 909 students who took the course between 2009 and 2012. These students performed a hands-on design project that involved toys, but did not use the video game. The second group was the 58 students who took the course in Fall 2012 and Spring 2013, and who did both a toy-based design project and the video game-based project.

Due to the small sample size for the video game group, only three of the subscales were found to show statistically significant changes (two-tailed test significance less than 0.05). For two of those scales: Technology self-efficacy and Communication self-efficacy, an increase in mean rating was observed, while the third, Engineering self-efficacy I, showed a decline. The larger toy-only group showed statistical significance in the following subscales, with all showing an increasing trend from pre- to post: Teaming self-efficacy, Technology self-efficacy, Communication self-efficacy, Engineering self-efficacy II, Feeling of inclusion and Coping efficacy. These results are shown in detail in Table 2.

While some favorable results were seen for the video game group, there are some obstacles to interpretation. There is a relatively small sample size, with lower initial means. Additionally, the video game sections of the course had a different instructor than the rest, and one section had a slightly high number of sophomores. What we do conclude is that on the whole, the toy project provided benefits to students in some of the measured areas, and that the video game preliminary data shows gains, but would benefit from additional investigation.

Some subjective observations from the implementation of the project are worth considering. Students were extremely enthusiastic about the game. They frequently arrived at class early in order to play. In the first section using the game, students were given more time with the game and were primarily allowed to discover the orbital mechanics through free exploration. Some students began to express difficulty with this approach, and supplemental instruction was provided. The second group of students were provided with some orbital mechanics instruction early in the project, and qualitatively seemed to have a better experience with the task.

Another important qualitative observation is related to the engineering design process learning objectives. Because of the somewhat specific nature of the defined task (producing a rocket to orbit the moon), students seemed to have difficulty understanding how the game fit into the context of the four-step design process. An intervention was used during the second implementation of the project to provide a more concrete explanation of how the design process was relevant to playing the game. After this intervention, students offered informal feedback that they now saw how the process fit into their natural gameplay activities and felt that the game was a good example of the process.

One design process feature that the game demonstrated particularly well was iteration. All of the student groups identified iterative elements on their way from testing of multiple prototypes to the design of their final rocket. No groups were successful from their first launch and all had to make improvements on the basis of observations of the design weaknesses. We felt this was one big advantage over hands-on classroom design projects in which expense and time constraints can preclude students from building and testing multiple prototypes.

TABLE II. SUMMARY OF SURVEY RESULTS

	Toys-Only Group (n = 909)			**Toys and Video Game Group (n = 58)**		
Subscale	Pre-Mean	Post-Mean	Diff	Pre-Mean	Post-Mean	Diff
Team self-efficacy	7.09	7.56	+0.47	NS[a]	NS	N/A
Tech self-efficacy	7.44	8.00	+0.66	7.26	7.80	+0.54
Comm self-efficacy	7.51	8.03	+0.52	7.32	7.94	+0.62
Engr self-efficacy I	NS	NS	N/A	4.77	4.53	-0.24
Engr career expect.	NS	NS	N/A	NS	NS	N/A
Engr self-efficacy II	4.91	4.98	+0.07	NS	NS	N/A
Inclusion	4.37	4.69	+0.32	NS	NS	N/A
Coping efficacy	4.90	4.98	+0.08	NS	NS	N/A
Math outcomes	NS	NS	N/A	NS	NS	N/A

[a] NS - Not statistically significant

V. CONCLUSION

The use of video games in the classroom is thought to have a great deal of potential to increase student engagement. We tested the use of Kerbal Space Program, a video game simulation of space travel, in a first-year engineering design project. Students were found to have enjoyed the project and were enthusiastic about the opportunity to play games in class. Some recommendations about the use of this game can be made on the basis of our experience. Students needed some guidance to understand the link between the video game and the academic content that it was meant to illustrate. However, once students began to feel comfortable with this relationship, they did observe features (such as rapid iteration) that the game was able to uniquely demonstrate. Survey data collected for the project showed that the game brought student gains in technology and communication self-efficacy ratings, and a decline in engineering self-efficacy. We believe that the outlook for this type of project is favorable as a demonstration of the engineering design process or similar activities, and that greater benefits to student participants can be realized with more experience.

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DISCLAIMER

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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