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Integration of Gamification and Creativity in Engineering Design

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Creativity is essential to innovative design, and is a crucial ability for engineers to exhibit[1]. This ability leads to new and useful products, processes, tools, and techniques for improving our lives[1], while also allowing engineering firms to remain competitive on a global scale[2]. Creativity is also an important part of the graduate attributes required across accredited institutions in North America, specifically in relation to design education[3,4]. Students are expected to develop the ability to develop innovative solutions to open-ended engineering problems, while designing with specified constraints. These attributes also specify that creative application of scientific principles is what differentiates engineering from natural science. However, students are often focused on fulfilling requirements and constraints necessary to achieve high grades, rather than emphasizing creative ways of apply their knowledge. Past studies have shown that while engineering instructors value creativity, they believe it to be lacking in their students, while at the same time current engineering students do not think that creativity is valued by their professors[1]. Similarly, while there is a greater industry emphasis on recruiting creative engineers and a greater interest in creativity from new engineering students, related literature questions whether or not postsecondary institutions are teaching creative thinking to their engineering students[1]. Postsecondary institutions must consider how creativity will be integrated into technical content in order to graduate engineers capable of leading the future.

Creativity can be defined in many different ways, and is often confused with simple problem solving[5]. North American engineering institutions such as Ohio State University and Purdue University have developed tools for assessing creativity within an engineering design context[2]. These types of tools are important assets for instructors attempting to incorporate and grade creativity within a design curriculum, and also provide recommendations for integrating interdisciplinary creative skills. Creativity can also be integrated through entrepreneurial product development and gamification. Gamification is the process of applying game mechanics to technical learning, often found in computer and software engineering[6]. This paper will explore an on-going design development process at the University of Calgary for integrating gamification and creative thinking with technical design techniques. The objectives of this work were to use gamification as a method of expanding opportunities for creativity and to engage student innovation. This paper will describe the four stages of the current research, results and observations of the various project iterations, and plans for future work.

Methodology and Analysis of Research Stages

This multi-year study began in 2012, with the latest results expected in April 2015. The entire research methodology has been separated across four main stages of work, starting with the first-year design course and later moving into advanced design courses in the department of electrical engineering.

Research Stage 1: Incorporating Games into the 2012 First-Year Design Course

At the University of Calgary, all first-year students are enrolled in a mandatory introductory design and communication course, ENGG 200. This class is their first experience with engineering design and hands-on team project work. Students work within a team of four

throughout the semester on several projects, ranging from three-hour design challenges to multi-week projects with detailed and complex task requirements. This course runs for thirteen weeks, and includes both a lecture and laboratory component. It was chosen as the initial situation for testing due to the flexible project environment and the heavy emphasis on design.

In 2012, ENGG 200 students were asked to create a computer game as one of their multi-week design projects. Students were asked to choose a client market, and then to justify their resulting design specifications, decisions, and game mechanics for the target audience. Few restrictions were built into the project, allowing teams to exercise as much creativity as possible. A free game creation platform was suggested and made available, but students were free to use any software or environment they preferred. The development process lasted several weeks, and students were graded throughout the evolution of their game on documentation, first prototypes, and initial testing. The final testing period was done during a three-hour lab session. Each team was required to explain their design choices and how they related to the client market. A teaching assistant then played through the game, noting bugs, glitches, design difficulty, and general enjoyment. All of the game levels had to be accessible to the teaching assistants, regardless of skill or familiarity with computer games.

In each team of four, students were responsible for dividing the work appropriately among themselves. The project deliverables required evidence of equal team member participation, including a team management document and presentation component. A group specializing in engineering teamwork psychology also provided material for the students to appropriate handle team conflict resolution. Teaching assistants were also engaged in ensuring that students were contributing during lab time. Students reported that while it was difficult for four people to work on the code, peer-programming techniques allowed multiple team members to write code, alongside the work needed to complete the testing, documentation, and presentation deliverables.

Students were also graded by their peers. Each team rotated around the room and attempted each game in their lab section, giving each other team an anonymously reported grade. The game prototypes were graded on three main aspects: does the game satisfy the client market, is the game well designed, and is the game fun to play. While a basic rubric was provided, students were encouraged to consider the creative and engaging qualities of each game. Overall, students were tough on their peers, often giving grades lower than the teaching assistants. Recognizing the potential for innovation and expansion, students expected to see high quality from themselves and others. Overall, the game project was received well, and students reported feeling accomplished when they were able to watch others playing and enjoying a final product of their own design.

Following the end of the course, students were asked to complete a survey relating to their perceptions of engineering. This anonymous questionnaire was distributed via an email link, and resulted in 144 responses. 36.8% were female, 24% were male. This survey was again repeated following the 2013 offering of the course, this time with 45% females and 55% males responding. Students were asked about their interests outside of engineering, their perceptions of engineering as a career, and their thoughts on course material. Regardless of gender, students in 2012 and 2013 identified computer games as their second most likely hobby, following sports and athletics.

Students also perceived engineering in a generally favourable way, with the majority agreeing or strongly agreeing that engineers are respected, design cool things, and help society. 86% of students also agreed that engineers have to be creative, showing a perception that engineering is an innovative career. However, only 58% of students disagreed that men are less creative than women, while only 80% of students disagreed or strongly disagreed that the best engineers are men and only 70% disagreed that engineering skills come more naturally to men. These results are shown in Figures 1 and 2. While students showed a bias towards engineers being creative and men as engineers, they did not show the same association towards men and creativity. This is possibility due to a perception that creativity is a feminine artistic trait, rather than an expression of innovation and design.

Research Stage 2: Expanding Games in the 2014 First-Year Design Course

The game design project was revisited and expanded during the spring of 2014, and later implemented in the fall of 2014. This iteration of the project focused more on the use of game mechanics to demonstrate an engineering problem and solution. Students were required to follow a specific theme this time, which was tied into all of the course projects. This theme was based on a book by Andy Weir called *The Martian*, which explores the struggles an engineer astronaut must undergo after he is stranded on Mars during an exploration mission. The game project required students to design and implement a game based around an engineering concept related to Mars exploration. This concept could be taken directly from the book study, or could be a real tool, technique, process, etc. currently used in Mars exploration research. The grading and testing process were very similar to the previous iteration. However, this year the students were allowed to choose between the game project and a more research-based design project. The engineering perceptions survey from the past years was again repeated, and additional follow-up questions were asked of the students who completed the game project.

Overall, the 2014 students' perceptions of engineering, creativity and gender did not differ from those of the past two years. Students again agreed that engineering is a creative career, but that men are less creative than women. This data has been summarized alongside the results from 2012 and 2013 in Figures 1 and 2.

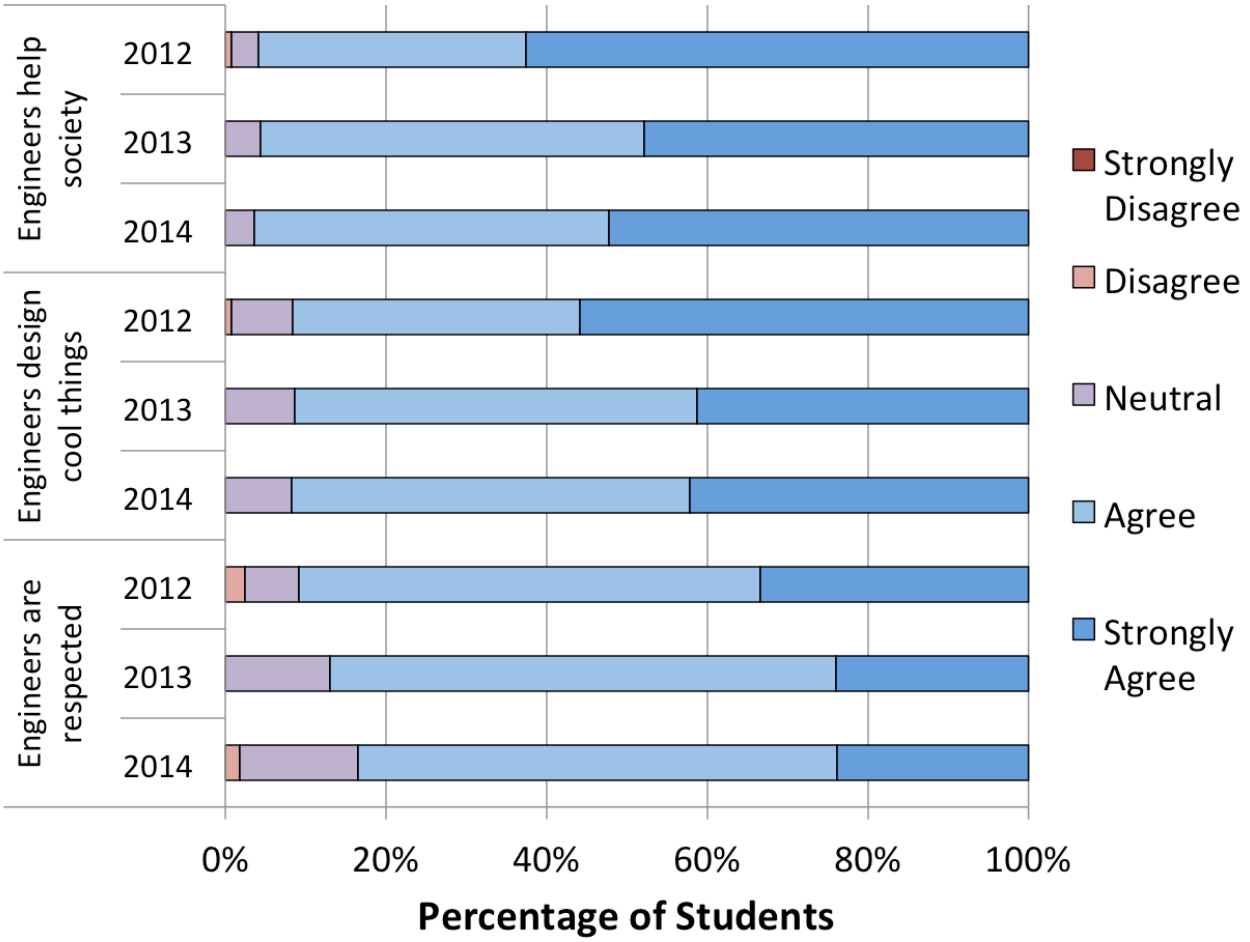

Figure 1: Overall, students perceived engineering as a respected career that involves designing cool things and helping society.

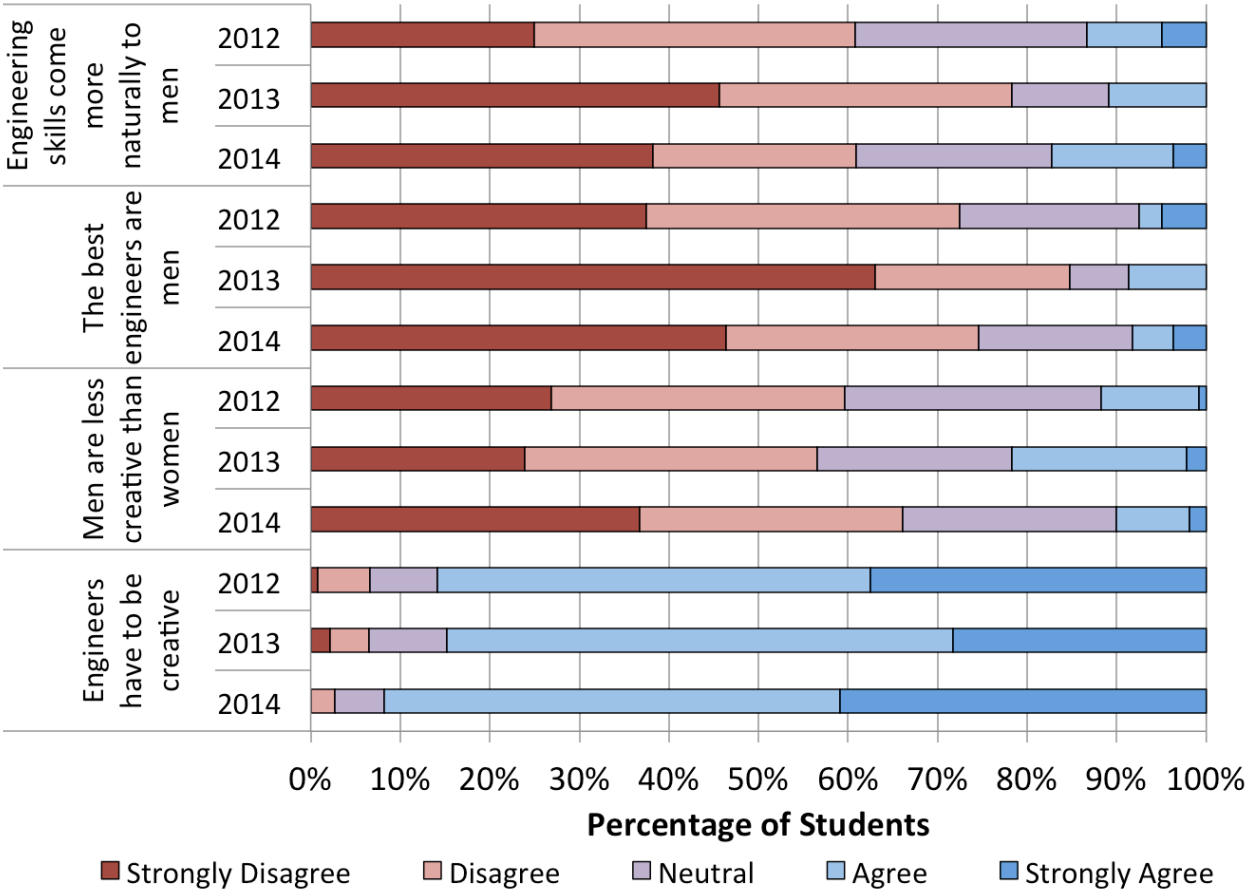

Figure 2: A summary of student associations towards male engineers and creativity.

Students who participated in the game project also reflected on their experiences and learning. On average, 85% of students agreed or strongly agreed the game project was creative, and 71% said they enjoy creating games, while 80% enjoy playing games. Interestingly, more of the female students enjoyed creating games at 90%, rather than the 63% of males, while both genders enjoyed playing games equally as much. Just over half of the students agreed that they learned about engineering through creating a game, and only 14% disagreed that the game project was related to real engineering. While these results were preliminary, they showed potential for game creation as a vehicle for incorporating creativity and engagement into design education. Additionally, students appeared to value the creative opportunities that gamification offered. When asked why her team chose to complete the game project instead of the research-based project, one student said "Because it seemed funnest and there was more room for my creative side". In comparison, a student who chose the research project said afterwards "The designs wanted were very specific compared to the specifications provided. Therefore, it was very tough and unenjoyable to know what was expected of us."

Another student reflected on the lack of creativity in the project that followed the game project, and its want of innovation.

> "I felt that very specific requirements take our focus away from thinking outside the box. I would make project 4 a little more general and not too specific to let the students think

in their own creative ways to come up with amazing things that they cannot do with the requirements or expectations that were outlined for the given project."

Students seem to equate creativity with flexibility in form and aesthetic elements. Despite having a specific design task and target client market, some students reported the game project as being more creative than other course projects, possibility due to the freedom in final format and the opportunity to incorporate their own interests and entertainment appeal.

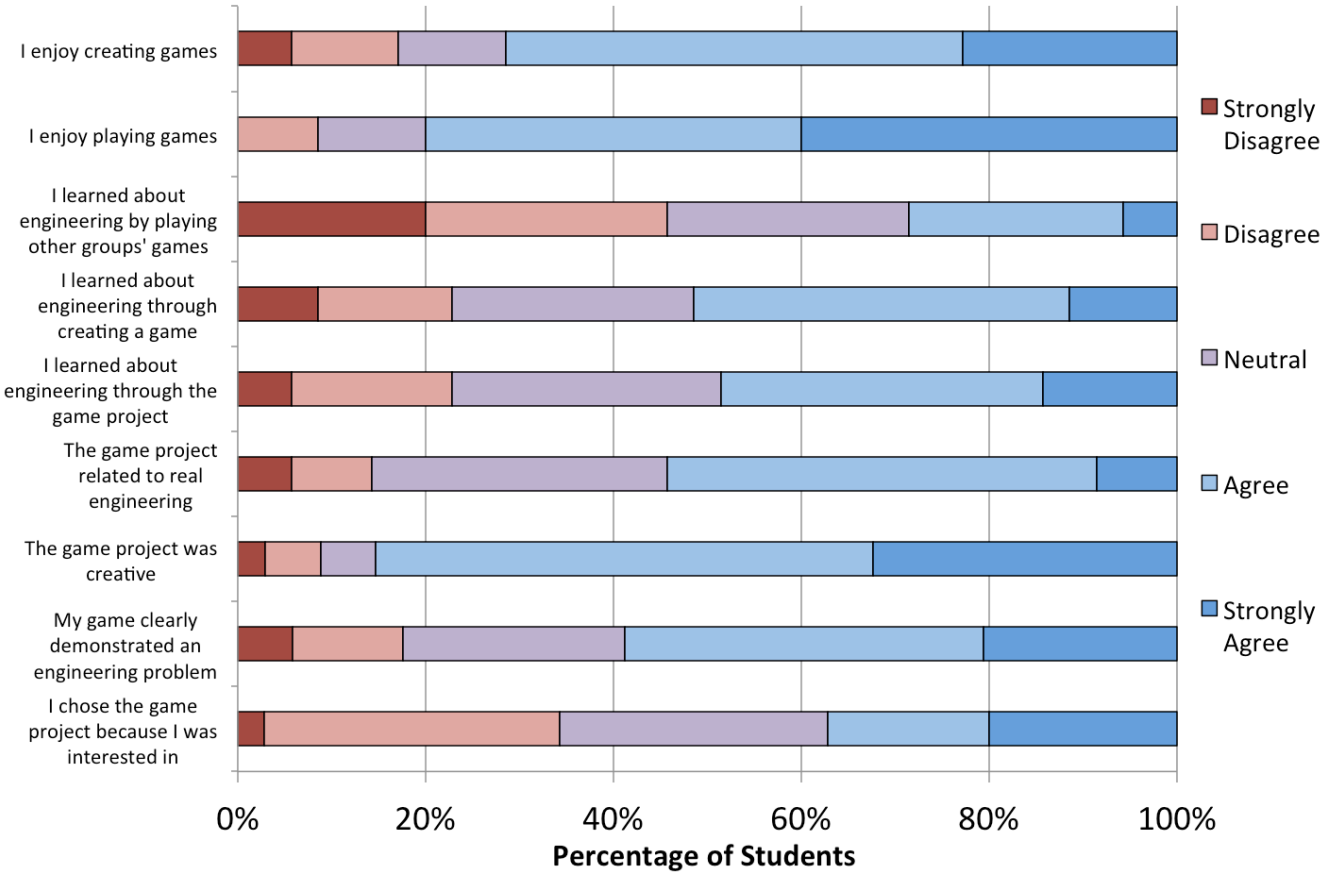

Figure 3: A summary of the reflections held by students towards games and the game design project.

Research Stage 3: Using Gamification for More Advanced Technical Design

Over the summer of 2014, the game design project was modified for application to a specific curriculum area. Undergraduate research assistants who had just completed their second year in electrical engineering tested this new project over four months. During this time period they were asked to design and develop a software game application that featured a circuit design technique while considering game mechanics, education, and entertainment aspects. Despite these students being new to the area of electronic circuit design, their innovation and creative abilities were observed alongside their technical learning.

After only four months of work, the students were able to create fully functional games capable of being run on an iPad. These games required the user to manipulate circuit design floor-planning and routing algorithms to achieve an optimal solution and score. The students also reported immense satisfaction at completing their games, and were pleased with the aesthetics and game mechanics as well. One particularly creative student wanted to include a more interactive atmosphere and incorporated background music and action sounds into his game. Colours, sound, scoring system, and graphics were just some of the elements used to develop an entertaining user experience while still teaching the player about circuit design. Most importantly, the students reporting feeling more motivated to work through the technical challenges because of their desire to expand and explore the game creation aspect of the project. Having a creative outlet and goal allowed them to focus on a final product, rather than on the smaller technical steps. The students also reported enjoyment and motivation due to the entrepreneurial nature of game design, and went through the process of making their games available through the Apple application store[7,8]. Screen captures from these games can be found in Figure 4.

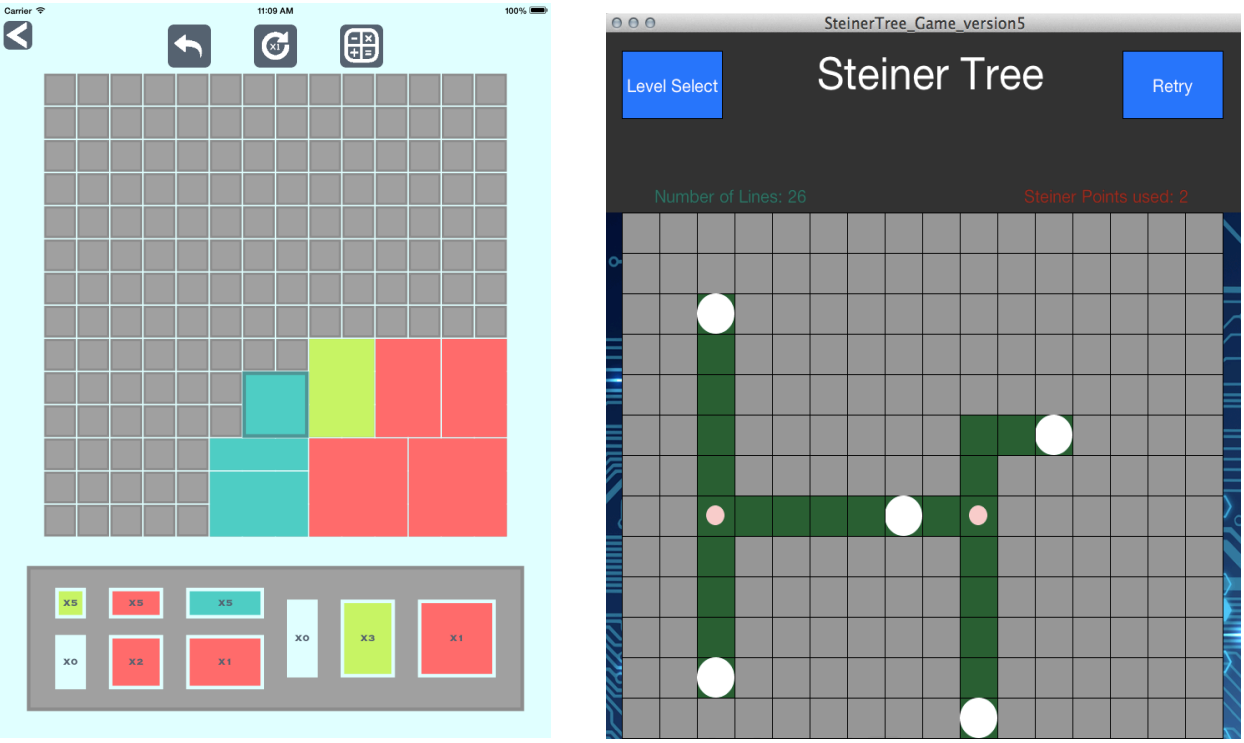

Figure 4: Screen captures from two of the summer games developed based on circuit design algorithms.

Research Stage 4: Current Work in Advanced Technical Design Courses

Following the positive results in Stage 3, the gamification education curriculum has been expanded for use in a fourth-year electronic design automation course. Students are once again challenged to develop a software-based game that uses an electronic design automation

algorithm, with additional considerations of a target client market, game mechanics and play, educational value, and aesthetic appeal. Students are allowed to work in varied team sizes, and were provided with the original code from the results of Stage 3. Students must complete a storyboard, project report, and basic implementation of their game idea. This course is currently running, and final results are expected by April 2015.

Final Conclusions

Overall, this work has found gamification to be a valuable method of introducing creativity and innovation into design education. Students are able to learn about the design process and technical challenges while still feeling motivated and engaged due to the elements of fun and entertainment in game mechanics. Future plans include additional gamification testing in other advanced engineering courses, summer camps, and among the public. This work will continue to emphasize the use of creativity within circuit design, helping to create new engineers who are capable of becoming leaders in their fields. Concepts from this research will also be integrated into community initiatives, including school visits, science centre collaborations, demonstrations, and workshops. The results shown in this paper support gamification as a positive method of introducing creativity and innovative into design education, while engaging and motivating students through difficult technical challenges.

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