Student Perceptions of Engineering Based Upon Board Game Participation

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Student Perceptions of Engineering Based Upon Participation in a Board Game (RTP)

In the past decade the demand for science, technology, engineering, and mathematics (STEM) professionals has increased significantly [1], thus creating a demand for improved STEM education. Often young students are not engaged by science and mathematics in the classroom through traditional teaching techniques (i.e. lectures) [2], as their learning styles are not always considered. Felder and Silverman [3] summarized the different learning styles which include visual/auditory, sensory/intuitive, inductive/deductive, active/reflective, and sequential/global. Complementary teaching styles can be matched to each of the learning styles, and the traditional "chalk and talk" style can in no way encompass all of them. Several institutions found that a mixed-mode approach which balances active learning and passive learning is best for teaching students, especially in early stages of development [4]. Thus, in order to teach STEM topics to all students, supplementary teaching tools should be utilized.

There are some assignable causes linked to the lack of engagement and success in STEM classrooms. Many times teachers themselves do not have adequate training to teach STEM topics. This problem was illustrated in a study done in 2007 that revealed the United States ranked 41 out of 46 in the fraction of math teachers with mathematics degrees; only 47.3% of teachers in the U.S. were properly qualified [5]. Teachers have also been known to follow a didactic teaching approach, teaching theory, then deriving the necessary equations, and then giving examples. This teaching style works for some, but does not actively engage all students. Research shows that students remember more when they are actively learning; they only retain about 20% of what they hear, and they retain about 90% of what they say and do [6]. This claim supports research done by Hattie et al, which states that teachers are most effective when they interact with their students in an adaptive, genuine way [7]. In order to increase the amount of interested, proficient students in STEM classrooms, teachers should be properly trained on every subject they teach and have tools to help them convey the information in an engaging way.

Game-Based Learning

One technique that has been used to stimulate learning in the classroom is the use of educational board games. Game-based education has the ability to encompass cooperative interaction between players, open ended problems, trial-and-error practices, pictures and prompts, and active/reflective learning [6].

A study done by Pippins et al., for example, explored the effects of implementing a chemistry board game in the classroom of tenth-grade students in Texas [8]. The study was done on approximately ninety-five students who were introduced to the game "Element Cycles", a board game that focused on the cyclic nature of elements in the environment. The students were given time to complete a homework assignment that required them to research some of the elements in the game and chemical concepts. They were then given a pretest, played the game, and then took a posttest to determine how well they retained information from the game. Results showed that the students who participated in the AP Chemistry course showed more improvement from the pretest to posttest (23%) than the regular Chemistry class (12%). These results were not compared with a control group, so no statistical analysis could be done for comparison.

However, trends in the data suggested that the game improved the student's ability to retain information, and the teachers observed student engagement throughout gameplay.

Another example of game-based learning in the classroom was a board game implemented in an undergraduate setting in an organic chemistry course [9]. The design of the board itself was modeled after an exothermic reaction. Each space was a different color and referred to a specific style of question. Along the reaction path, certain spaces would indicate the stage of the reaction, such as transition state, intermediate, and product. The players would roll a die to determine where they would go along the path. The winner was not the first person to reach the end of the reaction the fastest, but the person who had the most correct answers along the way. This teaching approach and reinforcement of concepts taught throughout the course had a positive impact on the students. The game was introduced prior to the students taking a test for the course, and the students who were exposed to the game received better overall test scores than those who only experienced the typical "question and answer" review sessions. The participants enjoyed the game and looked forward to playing it as a part of their review session [9].

Communication and teamwork within student groups, which are key learning objectives within the STEM field, can also be improved upon with game-based learning. Qualters et al. studied the impact of a board game called Shortfall on a group of sophomore-level engineering students [10]. The game was played by twelve volunteer students for 90 minutes, and pre/post surveys were implemented to gather information on the student's knowledge of supply chain management and confidence in their answers. Shortfall was played by teams, each comprised of a CEO, production manager, environmental manager, and R&D manager. Each team member had the responsibility to allocate resources and manage waste within a manufacturing company to maintain the greatest profit by the end. Teams were faced with challenge cards that sabotaged their success or added new rules to each round. The surveys showed that the game improved their overall knowledge of supply chain management and the role of communication in the engineering field. Quantitative analysis showed students' knowledge gain varied between questions from +0.08 to +2.42. The student's overall confidence in their answers also increased for 8 out of the 10 questions presented. Focus group results emphasized that the game helped with communication and teamwork more than concrete engineering concepts. Students also suggested that the competition aspect of the game made them more interested. The results of the study are important because students had limited time and no previous knowledge of the material, and in this instance, demonstrates that game-based learning, if nothing else, improves communication and confidence when learning new material.

These elements of experiential learning and best practices associated with game-based learning were considered when designing the board game that was implemented in this study. The objective was to create a game that incorporates both visual and kinesthetic learning styles to teach middle school students about engineering, while keeping the material engaging. How well this objective was met was assessed by its ability to effectively introduce engineering principles, engineering careers, and the valuable role women serve in the STEM fields, measured through a qualitative analysis of student responses to a provided worksheet. This study addressed the following research question: *is game-based learning an effective means of introducing engineering to middle school students?*

Methods

Game Design

The goal of "A Tour Through Four", the engineering board game the research team designed, was to introduce middle school students to engineering through a hands on, game-based approach. The name "A Tour Through Four" was selected since it provided middle school students with an overview of four specific engineering disciplines: civil, mechanical, chemical and electrical engineering. In the game design process, the team took inspiration from other common board games in order to brainstorm a game design and board layout which would keep users interested and convey key engineering concepts. The team examined nearly a dozen different board games, including popular games such as Candy Land, Mario Kart, and The Game of Life. The team determined the gameplay in Cranium™ was the most similar to the desired gameplay. Cranium was a good combination of multiple styles of gameplay. It incorporated trivia based questions similar to Trivial Pursuit, team based challenges, and creative thinking with drawing and sculpting similar to Pictionary. The team felt the trivia card layout was both educational, engaging, and able to present information in an effective manner. The game also incorporated team building opportunities, such as charades and drawing competitions, which promoted verbal and non-verbal communication between players.

Based on the research, the team created a game board design and set of instructions for gameplay that incorporated both visual and kinesthetic learning styles, which were displayed through the different types of questions presented and the physical gameplay (Figure 1). The game went through several revisions during development. First, a prototype of the game board and its instructions were given to peers and academic advisors for feedback regarding the game's physical layout, clarity, and areas of potential vagueness. After reviewing the feedback from advisors and peers, the team revised the game layout and instructions to finalize it for review with a focus group of middle school students. The team then collected verbal feedback and suggestions from the group of middle school students. After collection of this feedback the board and instructions were revised one additional time, implementing the students' suggestions and making additional alterations to improve clarity.

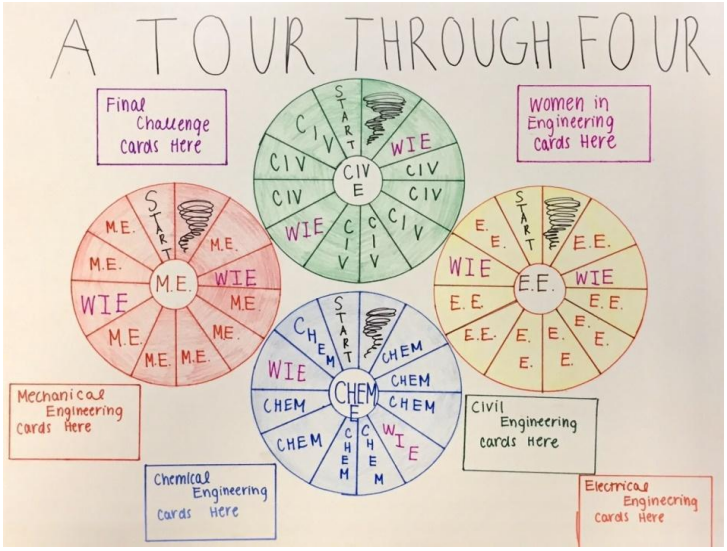

Figure 1: Finalized layout of the board game

Once the layout and instructions were finalized (Figure 2), the team began developing trivia questions focused on the 4 main disciplines of engineering: mechanical engineering, electrical engineering, chemical engineering, and civil engineering. Research has shown that by presenting students with only the four major disciplines of engineering rather than many sub-disciplines, it is easier for students to better compartmentalize and understand the concepts presented [11]. In addition to the discipline specific trivia cards, the team also developed "women in engineering" trivia cards. These cards explore historical and current women in the engineering and technology fields in order to expose middle school students to the vital role women have in these areas. Aside from the trivia based questions, the team also consulted online educational portals in order to find appropriate activities to act as "final challenges" or problem solving activities for the students [12]. These "final challenges" were word games and math puzzles that encourage critical thinking, teamwork, and technical problem solving.

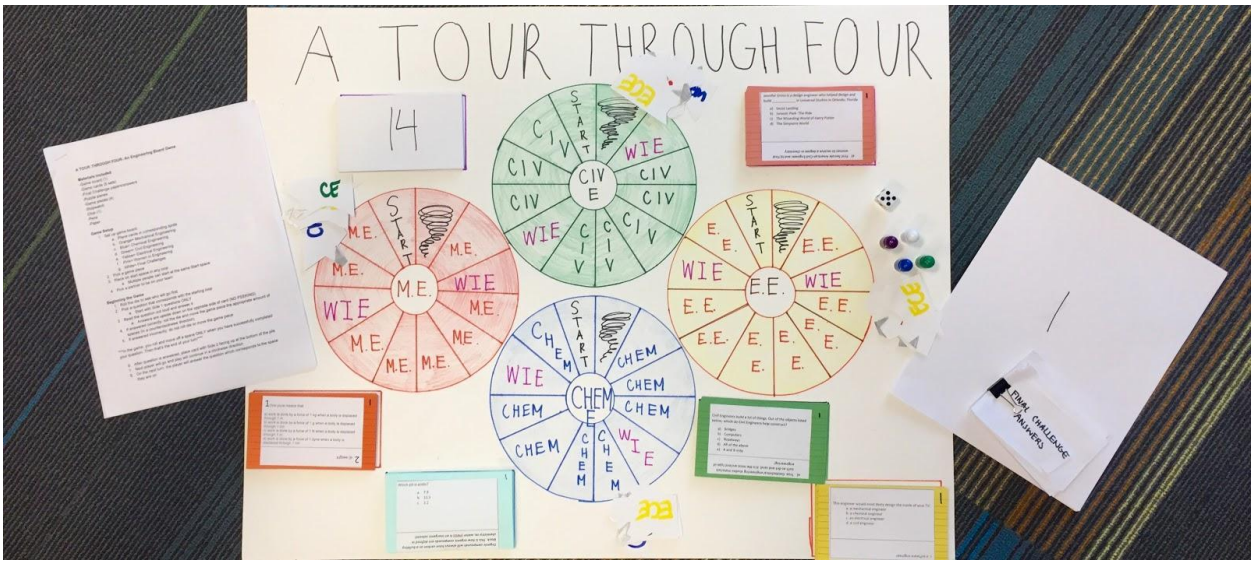

Figure 2: Board game and all components. This is the format that was presented to the middle school students.

The final board game and all of its components were reviewed to ensure the finished product met both the educational standards and project goal of a functioning game for engineering enrichment for middle school students.

Study Design

In order to test the functionality of the game and measure its ability to meet the proposed goal of effectively introducing technical concepts, the game was implemented with participants of an engineering after school program. This program is run by a northeastern university's College of Engineering Outreach Department with the goal of increasing interest in and exposure to engineering for middle school students. The program brought in 20 middle school (grades 6-8) students, representing a variety of ages, backgrounds, and genders, from the school districts in the surrounding area.

The game was run over the course of an after school program session. On the day of gameplay testing, the after school program students broke into 3 different groups, with 4-8 people in each group. The members of each group broke up into either single player or teams of two players, set up the game boards, and began gameplay. A member of the research team was present with each

group in order to answer questions and clarify any points of confusion, as our earlier research noted the importance of this presence for successful game implementation [13]. An hour was allotted for the groups to go through and play the game.

After the hour was finished, the research team members left the room, and a member of the after school administrative team distributed the feedback worksheets to the participants. The research team members stayed outside of the room until all of the worksheets were complete and collected. Proper human subjects' clearance was obtained prior to the conduct of this study.

Assessment Instrument

To measure the effectiveness of the board game implementation, a worksheet was developed using the Review, Summarize, Question, Connect and Comment formative assessment tool as a guide [14], [15]. The worksheet can be found in Appendix 1. This worksheet had the middle school students take time to recall something that stood out to them in the gameplay, summarize an experience they had while playing the game which made them think critically, ask any unanswered questions they may have had regarding the subject matter, comment on any aspect of the game they found motivating or discouraging, and critique something about the game. This worksheet is an effective tool because it allows the students to think about the information comprehensively and create links to the game and the information presented. The middle school students provided open ended responses to these questions which the team then used an emergent analysis approach to identify key themes within the responses[16]. Although the initial assessment of this game implementation was done using qualitative methods due to the small sample size, in the future when implementations are tested on a larger sample size a mixed methods approach that uses both qualitative and quantitative data analysis will be applied.

Data Analysis

The goal of the study was to determine whether game-based learning was an effective way of presenting engineering concepts and fundamentals to middle school students. In order to assess this research topic, the worksheet responses were content-analyzed using an emergent analysis approach. A qualitative analysis approach was selected since it allows for a deeper understanding of the student connections between the game and their experiences than could be obtained from a quantitatively focused questionnaire. Research questions that focus on connections between occurrences and why it happens are appropriate to this form of investigation [17]. The research team members reviewed all question responses but ultimately decided to focus on responses received to Question 1: "Recall something you have learned or something that stood out to you while playing this game. Did anything you have learned or experienced change your view of engineering?" It was determined that this question was the most relevant and provided the best link to the central research goal.

Once the relevant question was determined, the responses were examined using a grounded emergent analysis approach [16]. Two research team members independently reviewed all of the responses to Question 1 and compiled a list of all themes that were identified from the responses. After this process, the team members met and discussed their results and through a process of iteration combined their results to create a final list of themes that pertained to the data obtained from Question 1 on the worksheet. Table 1 shows the final list of themes identified from this analysis.

Table 1: Key Themes Identified from Content Analysis

Theme	**Description**
Engineering Principles	Students described a basic engineering concept (e.g. components of an electrical circuit, Newton's second law)
Women in Engineering	Student responses mentioned women in engineering or the lack thereof
Career Pathways	Students recognized how many different career options were available based on the engineering disciplines and subdisciplines

Reliability Analysis

Once the themes were identified, two different members of the research team reviewed all worksheet responses to Question 1 independently and coded them based on the key themes outlined in Table 1 above. The two research team members then came together to consolidate, discuss, and finalize the key themes that were identified in each participant's responses.

The inter-rater reliability between the two research team members on the coding of student responses was strong, with a Cohen's Kappa value of 0.788 where a value above 0.750 indicates a strong agreement above chance [18].

Results and Discussion

This study focused on answering the research question: *is game-based learning an effective means of introducing engineering to middle school students?*

Based on these worksheet responses it was concluded that students demonstrated awareness and knowledge about women in engineering fields, engineering concepts and principles, and engineering career paths and linked knowledge of these concepts back to their gameplay. Out of the 14 responses collected to the prompt "Recall something you have learned or something that stood out to you while playing this game. (Did anything you have learned or experienced change your view of engineering?)", 43% of students' responses (6 out of 14) fit the theme for engineering principles (i.e. mentioning a specific concept), 29% (4 out of 14) included references to women and their role in the STEM field, and 14% (2 out of 14) made a reference to learning about a new career pathway in the engineering field.

For example, some students' responses which indicated knowledge or interest in engineering principles mentioned being introduced to fundamentals such as the "formula of Newton's 2nd Law", different types of engineering such as "transportation engineering", technical components such as the names of "electrical pieces", and general scientific knowledge like the different sources of water for human use. These specific recollections are significant because they show that students were interested in or affected by a particular topic enough to remember a specific concept, which could indicate an increase in knowledge and awareness by the participants [10].

There were also multiple worksheet responses which focused on women in STEM fields, including “people should be more open to women working for engineering companies”, “only 14% of engineers are women”, and some students mentioned that they were “glad” women in engineering were included in the trivia aspect of the game because it was “deserv[ed]”. These responses show that the game provided exposure for students to the lack of female representation in engineering, an issue they may not have been aware of previously.

Students that participated in gameplay also demonstrated interest in engineering career pathways in their responses. One particular response stated “designing a snowboard… made me want to think to be an engineer”. This response linked back to one of the mechanical engineering themed trivia cards which asked students to identify a task that was typically not performed by a mechanical engineer. The options for answers were, “designing a snowboard”, “designing a safety harness for a roller coaster”, “designing the engine for a US Navy ship”, and “inventing bubble gum which makes it easy to blow a bubble”. In this case, the correct answer to the question was “inventing bubble gum which makes it easy to blow a bubble”. Although the question was aiming to teach students about a specific discipline in engineering, it also served the dual purpose of presenting different, non-traditional career options available in the field. In a similar study performed by Dave et al., girls were introduced to the idea of design work through recycled jeans. They learned about the different disciplines and how each discipline is applied in industry [19]. Providing young students with the tools to understand the diverse career opportunities in these fields can help encourage them to consider a STEM field for a future career.

Implications for Research to Practice

The testing of the engineering board game resulted in a few key findings focused on how technical concepts and STEM principles can be better introduced by educators in the K-12 space.

First, the study demonstrated the importance of presenting concepts in an engaging, hands-on way, especially to younger students. We found that students remained focused and actively engaged throughout the entirety of the game. They were exposed to new knowledge through the engineering trivia questions, experienced working in teams to solve problems, and exercised their critical thinking skills during the “final challenges”. Students enjoyed playing the game with some students even wanting to take the game home or back to school for continued play. These types of favorable reactions to the game, even while introducing technical topics, leads us to believe there are substantial benefits to teaching through a hands on, game-based approach.

In addition to the game being enjoyable as an exercise for the students, it also introduced them to technical topics related to different engineering disciplines. It is important to present these types of topics to younger students in order for them to better understand the STEM fields and relate these fundamentals to technical topics that they will become exposed to throughout their academic careers. We also concluded that introducing information about women in the STEM fields raised awareness by the students surrounding the lack of females in some of the STEM fields, both in present day and historically. Almost one-third of students expressed recollection or feedback in their responses regarding women in engineering and their disappointment with the lack of diversity in the field.

Study Limitations

Limitations for this study include the small sample size, the study setting, and the participant demographics. When testing the board game, we were constrained to the 20 students that participated in the after school program. These students did not necessarily serve as an accurate representation of all middle school students because they were pulled from an existing STEM program, did not cover a wide range of demographics, were predominantly one race, and were from a similar area in the northeast. The implementation of the game was only performed once due to the limited time the after school students visited the institution. The instrument selected for assessment is also not a validated tool at this time and would require further testing on a larger sample population to determine its validity. Additionally, although this implementation demonstrated that students were able to make connections between their experiences and different aspects of engineering, it is unclear whether this will be retained over time. Further longitudinal studies with this population of students would be necessary to investigate if this will occur.

Conclusions

Exposure to engineering topics and applications at an early age is imperative to the growth of the STEM field. Unfortunately, STEM topics are not always introduced in engaging methods within typical classrooms. The use of game boards in the classroom can be intriguing to students of many ages, and can convey information in multiple ways to reach several different learning styles. This study investigated whether game-based learning is an effective means of introducing engineering to middle school students. The game "A Tour Through Four" was designed to engage middle school students through trivia and hands-on final challenges. The results of the post-gameplay worksheet analysis showed that students were able to make connections about women in engineering, engineering principles, and the different career pathways one could take as an engineer from their experience with gameplay. These preliminary results demonstrate the potential benefits that can be achieved through the use of game-based learning for introducing STEM concepts to middle school students. Further development of this game will involve having middle school children assist with further design revisions, potentially broadening the use of Women in Engineering cards to include information on other underrepresented minorities within engineering and larger scale testing with the target population. All of these assessments will be necessary before more broad dissemination of the game is to take place.

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Appendix 1: RSQCC Assessment Worksheet

1. Recall something you have learned or something that stood out to you while playing this game. (Did anything you have learned or experienced change your view of engineering?)

2. Summarize an experience that you had during the game where you felt you were thinking/making decisions like an engineer. (What did you do? What types of decisions did you encounter? If your view of engineering changed, at what point in the game did it change?)

3. Do you have any unanswered questions regarding engineering?

4. Comment on an aspect of the game that you thought was motivating or discouraging regarding the concept of engineering. (What was your favorite aspect of the game? Least favorite? Was there an aspect of the game that made you want to learn more about the subject? Less about it?)

5. Critique something about the game. (What changes would you make to improve the game?)