Board 160: Discovering Simple Machines; Fun with Problem-Solving in Elementary School

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Discovering Simple Machines; Fun with Problem-Solving in Elementary School (WIP)

Introduction

This Work in Progress paper describes the first iteration of an engineering-focused educational board game design. This outreach activity for elementary students introduces the concept of simple machines, along with skills such as problem-solving and optimization of materials and cost. The board game, entitled "Simple Machinery Mashup,**"** is a hands-on activity that combines elements of design challenge with practical applications and comprehension checks. The game allows for the intended demographic of third-fifth grade students to explore and tinker with simple machines in a low-stakes environment that encourages teamwork and is driven by playful competition. Participants must create structures and answer questions using six physical models of simple machines and an array of additionally provided household materials, while also making tradeoffs and decisions about optimizing their budget and resources. To ensure that the board game is suited for the intended demographic and the educators that would be using the tool in class, a pilot test was conducted with four adults with backgrounds in elementary education. The participants of this trial run voiced their initial reactions and opinions in real-time via a simulated gameplay and questionnaire. Their comments and suggestions were recorded and analyzed to better understand what makes a successful tool for elementary educators and their students. The use of effective educational games and tools has the potential to instill interest in students and set them on a path towards a career in engineering.

Background

The introduction of engineering in K-12 education is crucial for instilling interest in and passion for the field in young adults as they enter higher education and the workforce [1]. The six most effective ways to introduce engineering concepts into early education include (1) hands-on learning, (2) interdisciplinary lessons, (3) implementation of state-wide standards, (4) training of K-12 teachers, (5) spotlighting engineers as role models and (6) prompting partnerships with external engineering programs [2]. Hands-on learning specifically instills interest in tinkering and allows students to make their own discoveries about new concepts that can then be applied to real-world situations [3]. In addition, using models and hands-on simulations can clarify small misconceptions about STEM topics that often go otherwise uncorrected [4]. Some of the most common methods to implement hands-on learning in the classroom include guided activities with models, experimentation, open inquiry, gameplay, and design challenges [5]. Guided play specifically can engage students in social fun with their peers while still fostering an interactive and educational environment [6]. Board games offer an opportunity for students to explore concepts and control their learning at their own pace in a low-stakes environment [7]. Engineering-related games can relate concepts to real-world applications and make tinkering and technology seem novel, promoting further exploration in engineering, science and math [8].

Board Games as Effective Educational Tools

Modeling engineering activities as a sport through large-scale robotics or architecture competitions has greatly increased interest in the engineering field over the past decade [9]. The allure of such competition can be replicated in the classroom through design challenges and board games. Design challenges such as LEGO engineering competitions increase motivation and allow participants to explore how to best optimize their materials [1]. Board games can also allow students to collaborate in small groups while also competing against other teams. Board games can promote teamwork, increase comprehension and learning achievement, and further self-efficacy and motivation.

Board games promote teamwork: Teamwork is considered an essential skill in engineering as it allows for complex problems to be solved efficiently [10]. Having good teamwork and collaboration skills instilled at an early age is a valuable trait to employers when entering the workforce [10]. In addition, board games provide playful, low-stress environments that give students the comfort and confidence to make mistakes and learn from each other [11].

Board games have the capability to increase comprehension and learning achievement of academic concepts: The structure of a board game allows for subtle reinforcement of concepts through repetition and practical application [11]. Third grade students in Taiwan that played an English vocabulary board game had significantly higher scores on a reading comprehension post-test than their peers who learned in a lecture-style course [12]. A similar study showed that eighth grade students in Bandung that played a social science board game had an n-gain score that was twice as high (0.59) as students who did not play (0.23) from before to after introducing the topic [13]. These results are not limited to young students. University of Campinas undergraduate students showed significantly higher exam

scores in a pharmacology course after playing an anatomy/physiology board game compared to those who just learned in a lecture hall, suggesting that board games can be effective at explaining and teaching higher levels of expertise [14].

Board games promote self-efficacy and increase motivation to learn: The same study on the English vocabulary board game showed that playing decreased learning anxiety and increased excitement and anticipation to learn [12]. Undergraduate students in a business course had higher resilience and self-esteem scores from before to after playing an entrepreneurship simulation board game [15].

The evidence of board games' capabilities to promote learning achievement, teamwork, and self-efficacy led us to create a board game to instill interest in engineering. Fostering a low-stress, engaging environment where students may explore engineering concepts has the potential to set them on a path of passionate interest later on in life.

Simple Machinery Mashup: Building the Basics

Our team has created a board game that introduces concepts in engineering to students in grades 3-5. These concepts include simple machines, material and cost optimization, and problem-solving. The board game, entitled Simple Machinery Mashup, is an exploration of simple machines with elements of design challenge to perform elementary tasks. The game prompts participants to explore the practical application of simple machines in a setting that encourages optimization and problem-solving. Simple machines are defined as structures that decrease the amount of force needed to do work [16]. The pulley, wedge, lever, wheel and axle, screw, and inclined plane are all simple machines and act as essential building blocks for complex engineering structures. Understanding how simple machines work, and how they can work together, are beneficial for visual spatial intelligence and thinking outside the box to optimize given materials [16]. The concept of optimization is seen in the board game through both limits on material usage and budget. Engineers must use optimization in everyday life to create successful plans and structures within given the parameters and constraints of budget and materials [17].

The game is designed as a cooperative team-based activity, where teams can compete against each other. Ideally two or more teams with 2-4 players each compete against each other to reach the end of the board first. Players are given five physical models of simple machines, along with a set of extra materials (from household items) such as a sheet of paper and rubber bands. Each machine and material has a set price, which players are allotted $200 to spend on as they move through each task.

A team begins their turn by rolling a die and moving their piece that number of spaces on the board. Each space has an associated activity: "Construct," "Swap," or "Quiz" space. The corresponding card is drawn (Figure 1) and the team then has two minutes to complete the given task or answer the given question. A "Construct" card gives the players a limited amount of simple machines to use and money to spend to create a structure that will perform the given task. A "Swap" card prompts the players to question the capabilities of each simple machine by essentially "swapping" the most logical tool for a specific task with another, and then testing if their proposed alternative works. A "Quiz" card asks the players a comprehension check question about simple machines. Teams can only move forward on the board if the question or task was completed correctly.

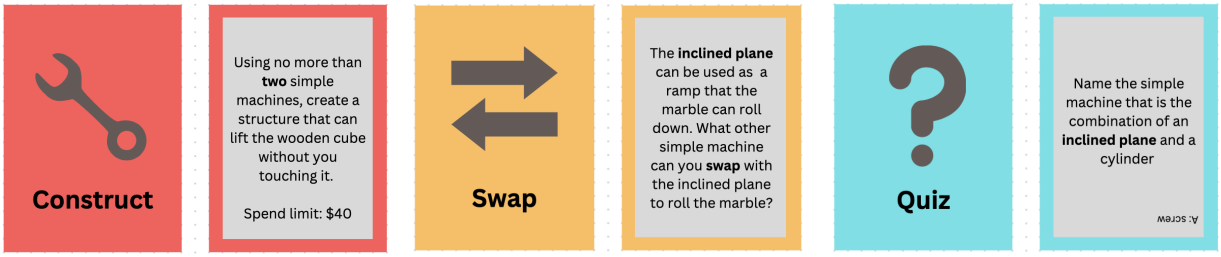

Figure 1: Examples of the three cards and possible prompts on each.

This paper describes the results of a trial run of the first iteration of the game, tested in an in-person think-aloud session with a participant sample of educators. Think-aloud sessions allow participants to give their unfiltered reactions and are meant to reveal "inner speech" to the observer, which gives insight into the thoughts of the participant that they may not remember and recount later on, but that are still useful for the observer to know [18].

Using this method allows for all of the necessary information to be gathered and analyzed, rather than just the main highlights that participants would think to relay after the game ended. These observations and opinions will act as points for improvement as future iterations of the game are produced, and then eventually tested on the intended demographic of third to fifth graders.

A participant sample of educators was chosen for this initial pilot of the game to ensure appropriateness of the intervention before testing it with students themselves. Oftentimes, research is presented to educators as pedagogical solutions that are subsequently ineffective and difficult to implement [19]. Collaborating and working closely with elementary educators allows for deeper, more authentic insight into the intricacies of classroom management and trends for student participation patterns [20]. Experienced educators are more attuned to what works best in real-life classroom settings and what students are inclined to enthusiastically respond to or misunderstand [19].

The results of this study supports a collection of guidelines for making an effective learning game or tool for classroom use. Creating effective, enjoyable and informative games to introduce engineering to K-12 students may set students on a path towards becoming passionate, curious engineers as they further their education and enter the workforce.

Materials and Methods

Four certified teachers participated in think-aloud sessions and voiced their opinions and reactions to elements of the board game as they played and were prompted with questions. Their comments and suggestions were recorded for future reference as new iterations of the game are developed.

Participants: Participants consisted of four certified teachers ranging from age 23 to 55. The years of experience teaching that each individual had ranged from one to 33 years. Two of the participants were male and two were female. The years of experience were balanced across gender in participants. Three of the four participants have a focus in STEM education, the fourth being a fine arts teacher. This range of experiences allows for diverse perspectives and an array of academic contexts to be considered in the trial run. Participants were recruited through word of mouth.

Data Collection: Data from the four participants was collected in two parts: 1) a modified think-aloud and 2) an immediate follow-up group interview. First, participants were led through a conceptual round of the board game by the researcher and were instructed to voice their initial reactions and opinions by thinking aloud. The physical game pieces were not provided, so participants explained and talked through what they would do if they did have the necessary materials. Each team had two players and competed against each other to reach the end of the board, just as the intended demographic would play. The researcher kept track of the comments being made during gameplay. Second, participants were asked a series of concluding questions after the game was complete in an immediate, semi-structured, follow-up group interview. The participants were encouraged to bounce ideas off of each other during this interview and share personal experiences to offer insight into what they felt could be improved about the game, along with what they liked and thought was beneficial.

Data Analysis: The qualitative data from the think-aloud gameplay and the follow-up interviews were recorded by the note-taker and then analyzed for emergent themes. Comments were separated by game element and learning principle as categories naturally emerged in participants' responses. The answers to each question are quoted and/or summarized into the primary concern and suggestion for improvement.

Results

Reviewers' comments and answers from the questionnaire and gameplay are recorded and organized in Table 1. These comments are summarized due to the collaborative nature of the data collection. Reviewers built off of each other's ideas to develop clear recommendations for improvement.

Positive Comments: All reviewers were in consensus that the game was suited well to the intended age demographic and that it could be a useful tool in classrooms. The hands-on nature of the game using physical models was said to be crucial for full exploration and understanding of the simple machines. Learning objectives are apparent in the activity, but the game is still enjoyable to play. This game could be especially useful as a lab exercise or for an exam review.

Concerns and Ideas for Improvement: A frequent suggestion was remodeling the physical board of the board game to be more interactive and engaging. Rather than using 3D printed physical models for materials, one reviewer suggested that participants find simple machines for themselves, in a common household or classroom environment. The concept of cost optimization could be more clear if the game was formatted to buy and sell the "inventions" that participants create rather than just by saving money. Other challenges could include time constraints or "wild" cards that add extra elements of problem-solving to gameplay. Drawing connections to real-world inventions using simple machines could be more beneficial than some of the other proposed prompts. Teamwork dynamics would need to be monitored to ensure that one participant does not take over for the group.

Game Element	Positive Comments	Concerns/Ideas for Improvement
Board	- Easy to follow - Aesthetically pleasing	- Construct the board with each turn for a more engaging experience - A circular board with many paths to the center to show there are multiple solutions to a problem - Pegboard with holes to stick game pieces into for ease of construction - Use app or virtual tool to play and experiment with machine capabilities rather than with physical materials
Simple Machine Models	- Physical models are crucial for understanding and gameplay - Hands-on nature of physical models gives participants opportunity to explore details	- Encourage students to find and/or construct their own simple machines with classroom materials, to show that they surround us - Include enough materials to support all structures; a stand for pulleys, four wheels and axles, etc. - Create pack of 3D-printing templates for educators to download and use instead of a board game
Construction Cards	- Shows that there are multiple ways to solve a problem - Hands-on construction is enjoyable - Allows for participants to explore machines' unexpected capabilities	- Include a time constraint or add an element to include halfway through construction - One or two "wild" cards in the deck give participants 2-3 machines to use, but they must decide the purpose their structure will fill.
Switch Cards	- Encourages participants to think outside the box about traditional uses	- Found that these cards became redundant after a short period of time - Could replace this deck with a prompt for participants to list examples of a certain simple machine in real-life
Quiz Cards	- Comprehension check - Some questions introduced new concepts not directly related to game play	- Quiz cards must be elaborated on as a group, as one participant may answer for the team while others don't know the correct answer
Learning Objectives	- Low stakes introduction to simple machines - Introduces optimization of materials by using machines unconventionally - Optimization of cost is seen especially near end of gameplay when money is running out - Good teamwork exercise - Problem solving and creativity	- Cost optimization could be heightened in a "Monopoly-style" format, in which participants buy and sell their inventions to move forward
Classroom Management	- Fits intended demographic - Useful lab activity, in which class is split into groups and play against each other - Useful test review	- Collaboration could be one-sided if teams are too large - More STEM oriented participants could easily dominate conversation - Pieces should be large for ease of use

Table 1 Comments and suggestions from four educators about different board game elements

Discussion

The comments and suggestions accumulated from the four educators offer insight into the most useful and feasible ways to introduce the concepts of simple machines to students in the target demographic. The key takeaways from the participants' feedback included introducing more opportunities for engagement, emphasizing that simple machines are found universally, and making gameplay more rooted in real-world situations with higher stakes. This feedback could also be useful in the curation of other educational games focused on STEM topics.

Increasing Opportunities for Engagement: During the conceptual gameplay, one of the most common suggestions was to introduce more ways for participants to engage with and explore the materials and game board itself. Modeling the board to be more circular, or with multiple paths to get to the end, could reinforce the idea that there are more than one way to solve a problem and get to a solution. Allowing participants to essentially build and design the board as they play could also emphasize the importance of their creativity and self-efficacy.

Highlighting the Universality of Simple Machines: Engaging with the simple machines themselves through hands-on exploration was said to be beneficial, but could be improved by removing the 3D-printed models entirely and asking participants to find materials in their home or classroom. Requiring participants to examine the world around them would reinforce the concept that simple machines are everywhere and would remove the idea that such tools need to be specially produced. This idea could also be emphasized by prompting participants to identify examples of simple machines in real-life structures on the "Quiz" or "Swap" cards.

Raising the Stakes: The theory that the target demographic would be confused by too many challenging elements was quickly disputed by the reviewers. Rather, they believed that the stakes of the game could be raised by including additional rules and game elements. Including "wild" or "challenge" cards adding elements of time constraint could potentially add another dimension of strategy and competition. Altering the game to include higher optimization stakes, such as by requiring participants to buy and sell inventions with their allotted budget to move around the board, would emulate successful engineering in real-life.

Align to Mimic the Real World: A common theme seen in a majority of the comments made was that the board game should be more rooted in the real world, with real-life situations and problems. It was explained by the reviewers that a typical critique of classroom activities or lessons is that they (the students) will never use that information in real life. Modeling the risks and rewards of buying and constructing products with available materials could potentially simulate this real-world dilemma, and could make participants feel as if they are truly creating something of their own rather than just playing a game for a grade. In addition, group dynamics and issues of teamwork were key issues of concern. Collaboration and healthy competition make for more efficient problem-solving and a higher likelihood to participate, but it is also not uncommon for participants to be excluded and subsequently not fully understand the topics presented. This imbalance was even seen between the four educators, as the fine arts teacher reported that she felt she was bringing her team down by lacking the engineering knowledge.

Conclusion

The creation of educational board games is an effective way to introduce concepts to students and set them on a path of passionate interest. When creating these games, it is beneficial to first consult the educators that will use them, as they know the behavior patterns and intricacies of classroom management best. The comments made by educator-reviewers suggested that it is important to create activities that have multiple elements of interaction and engagement, along with stressing that the systems and concepts modeled in the game have real-world applications that can be seen all around us. Alterations to the game based on these results have the potential to create a more effective board game and experience for elementary students. These comments have the potential to support the creation of more effective elementary educational games in the future.

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