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MakerGames: A Board Game to Help Facilitators Maximize the Educational Potential of Project-based Learning

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MakerGames: A Board Game to Help Facilitators Maximize the Educational Potential of Project Based Learning (Works in Progress)

I. Introduction

Teachers are looking for new ways to bring engineering into their classes as they adapt their curriculum to include new content from the next generation science standards[1] and the less tangible "21st century skills"[2]. Tufts University Center for Engineering Education and Outreach (CEEO) "works in the areas of outreach, research, and tool development to make engineering and design accessible and feasible in P-12 classrooms"[3]. In this study, funded by an internal grant from the CEEO's innovation fund, we have developed a game that integrates and scaffolds content knowledge of engineering design while allowing students to playfully engage in problem solving and teamwork skills.

Engineering education researchers have worked with P-12 teachers to understand their mental models of engineering and how professional development can help them identify engineering practices in their classrooms[4][5][6]. In Ann McMahon's key findings about how teachers understand engineering processes, one of her recommendations for curriculum development is to "scaffold teacher ability . . . by including a multimedia facilitator's guide or section for each engineering unit that makes explicit the engineer's mental models for enacting the engineering design process." Amber Kendall observed how teachers facilitated an engineering challenge in their classroom after a professional development workshop. She stressed the importance of teachers' attentional skills in listening to students and pointed out, "it would have been good to see more interrogating of student ideas and less noting." Formative assessment also influenced the game's design because it provides teachers opportunities to meta-cognitively examine their ideas and goals, helps students reflect on their learning, and develop the agency of other students as instructional actors (e.g., through peer to peer learning)[7][8].

Teachers	Students
1. The game sparks conversations that allow for a focused interrogation of engineering design concepts and scaffolds the content knowledge in an understandable way. 2. Conversations offer opportunities for teachers to perform formative assessments of student knowledge and interrogate responses based on individualized expectations. 3. The clock allows the teacher to help groups manage time constraints and allocate time to design activities, ensuring that all groups are ready for presentations at the game's conclusion. 4. Teachers exercise discretion regarding the dispersal of materials, and players are incentivized to think economically about the use of limited resources.	1. Students experience discussions around the gameboard as play rather than schoolwork. 2. Prompts help students "self select" the level of complexity with which they will engage with the design challenge; at the same time, peer to peer learning is an important dimension of group activities. 3. Engineering design content (knowledge) gained in the course of gameplay is formalized during presentations and shared with other groups. 4. Students engage in "21st century skills" (e.g. problem solving, critical thinking, teamwork) in ways that are visible to teachers and which can be tracked through formative assessments. 5. Student's focus is not on fulfilling teacher expectations (e.g., grades) but rather on playing the game.

Table 1. Design criteria for teachers and students considered during development of MakerGames

With these needs identified, we developed a game concept to help teachers scaffold the introduction of engineering content knowledge to students in the context of hands-on problem-solving challenges. We recognized both students and teachers as the clients or end-users of this game and developed goals for each population in Table 1. In this first case study, we assess the potential effectiveness of the newly developed tool, the MakerGames, by analysing how it was used in a workshop by players (students) and how it was managed by the game facilitator (a stand-in for teachers).

II. Background

Researchers, who have developed theories about best practices for introducing engineering design and “21st century skills”, have consistently identified the engineering design process (EDP) as an optimal tool for teaching problem solving skills[9],[3]. The EDP offers a framework for problem solving that enables critical thinking, focuses attention on quality of solution, and requires cognizance of constraints (material, financial, temporal, or other). The iterative nature of the EDP and the fact that, in practice, the EDP is not cleanly cyclical heavily influenced the game’s design. Any engineer inventively skips from one part of the process to another while designing and making, implying that revisiting a prompt about framing the problem can offer value even when you are in the middle of building.

The game also encourages a make believe mindset, encouraging players to *re-imagine themselves* as engineers, rather than to simply perform engineering tasks. We encourage this make believe mindset because this type of play has been shown to dramatically improve children’s focus and concentration, memory formation and recall, and behavioral regulation. One study on the value of pretend play showed that a child, aged five, who could not sit attentively for two minutes of circle time with his kindergarten class, could sit attentively for ten minutes when researchers created a game of “make believe school”[10].

III. Game and Case Study Overview

In its current state of development, the MakerGames is a physical board game with prompts corresponding to steps of the EDP forming the perimeter of the board. Each side of the board represents a segment of the traditional engineering design process: “frame the problem”, “make”, “evaluate”, and “share”. The facilitator sets a tempo for play by inputting the time each turn will last on a digital clock (Figure 1b). After rolling a die, the team discusses the prompt they land on with the facilitator within their allotted time, then takes a limited amount of building materials based on the facilitator’s discretion. This is how ordinary play unfolds. When there are roughly thirty minutes left for the activity, the facilitator signals that teams should prepare for presentations. This is a similarly timed process that is guided by prompts which culminates in team presentations. Additional information about the game and more details of how it works can be found at http://www.MakerGames.education.

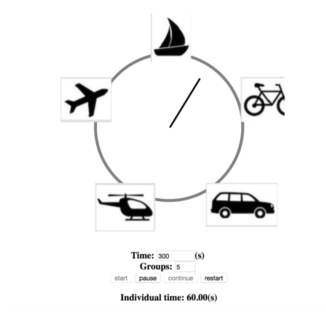

Figure 1a (left). Facilitator talking with a team at the board as the previous team collects materials
Figure 1b (right). Game clock that was used in the case study workshop for five teams

MakerGames is designed to support nearly any hands-on building activity. In the two hour weekend workshop used for our case study, the challenge was to "design and build an amusement park ride for a LEGO minifigure using LEGO and other found materials". The fourteen participants - five girls and nine boys from eight to twelve years old - were recruited for the free workshop from an email list of parents who follow offerings at Tufts CEEO. Participants were split into five teams. After a brief introduction to the challenge and the game, each team was asked to write a backstory for their client as they waited for the clock to reach their team's logo, signaling the start of their first turn.

During the case study workshop, we recorded the nine rounds of conversations each group had with the facilitator and each group's final presentation. We also photographed groups' fabrications and writings. The facilitator during the workshop was a PhD student in mechanical engineering and two additional CEEO affiliates were in the room to observe, record, and help when needed. Building off of the observations of the facilitators and the feedback they received from students, the recorded dataset was used to find anecdotes that told a story of how different participants interacted with and learned from the game.

IV. Key Findings

One of the first metrics we were interested in when evaluating the game was the students' level of engagement. While this is a difficult metric to substantiate given the limited scope at this stage of research, the game observers noted high levels of enthusiasm whenever a group was called to take its turn in the game. A few examples recorded on camera show students visibly exuberant about rolling the die. Additionally, there were only two turns throughout the game were a group took *more than* ten seconds to leave its workspace and approach the board for a next roll of the die. What was the root of this enthusiasm? We could speculate that it may have been the promise of more building materials, or it may have been the promise of seeing one's game piece advance around the board.

For a more detailed analysis of our case study data, we followed the trajectories of two teams through the game. They were chosen because each team landed on the same three prompts during the first three rounds of play. The teams also represent slightly different age groups. We were interested in how the two teams' interactions with the facilitator varied while discussing identical prompts. We also looked for concepts and statements introduced during gameplay that resurfaced during presentations, as well as for evidence of engineering thinking and signs of playful engagement.

Note that prior to the first round of play, the facilitator had asked teams to create a backstory for clients. These teams, therefore, had already begun narrating a story about their clients before landing by chance on the prompt "Describe the client and the client's problem". It is interesting that the "Ferris Wheel" team added the detail of the car crash despite its apparent lack of influence on the client or design, indicating a narrative or "playful" approach to the design challenge. The facilitator tried to respond to the "Ferris Wheel" team in a way that could make their client's backstory relevant to the challenge, while the "Boat Maze" team seemed to have a clear idea for their client and the ride design straight from the start.

"Describe the client and the client's problem"	"Name some design constraints"	"How will you measure success"
Facilitator: So who's the client? Student1: The client lives in Boston, he got run over by a car but he survived. F: Ok, what's his name? Student1: Bobby Joe F: Bobby Joe, ok - great. So what's his problem - he was run over by a car…. Student1: [can't hear] But he likes fast roller coasters. F: Ok, so… Student2: He like adventures, he likes going fast. F: [repeats student] So he got run over by a car. Does he have any disability? S1: He's fine now. F: Ok, so that's just part of his backstory? S2: Yea F: So anything else to know about his backstory? ...	F: Do you know what the word constraint means? S1: Yes! So ummm, it's like a thing that's stopping S3: A limit. F: A limitation, right. So right now…. S1: Time! F: Right, time is a limitation we have, so how long do we have to build? S1: Two hours. F: An hour, hour and a half. What's another constraint we have? S1: Materials! F: Materials, right. So do we have all the materials you want in the world? S2: No. F: So we should be thinking about these constraints as we are building...	S1: By how… We'll test it a few times and then we'll see how many times it fails. F: Ok, so you're thinking about the structural stability of it - whether or not it falls apart or stays together. S2: Yea. F: Is there any other way to measure success? How do you know if your client likes it? S2: If our client likes fast and scary, so if we make like a rollercoaster, we have, we're trying to make a car, like a cart, that would go fast. F: Ok. And how do you know if your client likes it? S2: Because if it's like pretty fast and our client might like it. F: So you're just going to trust that if it's fast your client is going to like it because you know he likes going fast? S12: Yea.
F: So who is your client? S1: It's a speedboat. F: A what? S2: He's from Boston and he loves boats. He also loves mazes and heights. F: [repeating students] S3: We're running out of time [looking at the clock]. F: And so, because he likes boats, is that going to play into your amusement park ride? S123: Yeah. F: Ok. Anything else to consider about your client and what he likes about amusement park rides? Does he like going fast? S2: He likes intense situations. He also likes going fast.	F: So do you know what a constraint is? S123: Uhhhh, no. F: Constraint is like a limitation. Something that's holding you back. So what are the limitations right now? S2: We don't have water. F: You don't have water, right. We can help you with that if you really want water. But, do you have all the time in the world to build your amusement park ride? S123: No. F: Do you have all the materials in the world to build your amusement park ride? S123: No. F: No, so as we start, should we try building an amusement park ride as big as the table? S1: Uhhhh, no. F: Probably not. We're going to try to make something within our time, within our materials, within our constraints.	F: How will you know if your ride is great? S2: If our client likes it. F: Ok and how will you know if he likes it? S2: Because he likes boats. S1: Because he doesn't die. F: He doesn't die, ok that's a good measure of success, safety. S1: He likes boats and…. S2: He gets back and gives us a star review. S1: He gives us a good review. F: Ok, a Yelp review maybe. You can ask the client what he thought of it, right, and if he doesn't like it very much is that a success? S123: No. F: Not necessarily. Ok, any other ways you can measure success? S123: Uhhh. F: Safety and client feedback? Is that the main two things? S1: Yea.

Table 2. Transcribed conversations of two selected groups. **Top ("Ferris Wheel" Team):** Student 1 (11y/o), Student 2 (10y/o), Student 3 (9y/o). **Bottom ("Boat Maze" Team):** Student 1 and 2 (9y/o), Student 3 (8y/o)

The conversation of constraints went a bit differently for each group, but the facilitator guided both discussions toward the concept that they should build something that could be completed given the materials and time available. The game offers freedom for facilitators (i.e., teachers) to direct discussion based on the context of the making activity and other teaching objectives.

The third prompt allowed the facilitator to interrogate evaluative engineering ideas more deeply with each group. Improvised follow-up questions helped shape authentic conversations about what metrics could be used to measure success. The "Ferris Wheel" group's response about not needing direct client feedback is an example of how a facilitator can identify areas of misunderstanding through formative assessment.

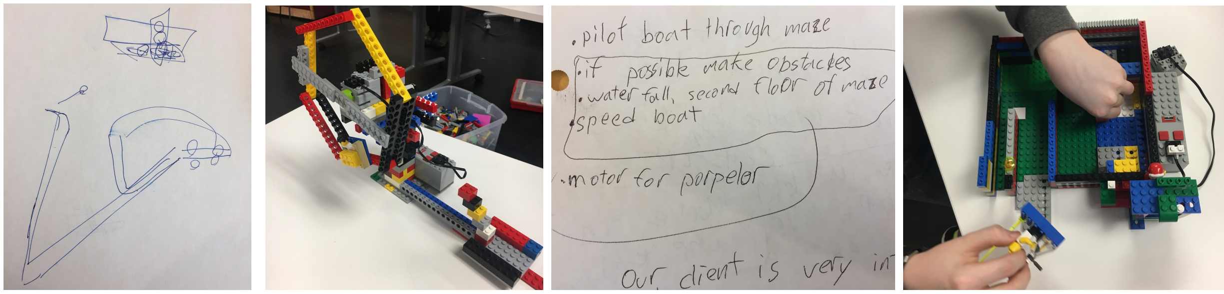

Figure 2a (left): A sketch done by the ferris wheel team showing the concept for the stairs used to get on their ride.
Figure 2b (left-center): Ferris wheel ride with a minifigure strapped into bottom and stairs on the right.
Figure 2c (right-center): A list found on the boat maze team's sheet with a list of priorities for their prototype.
Figure 2d (right): Boat maze with one of the group members holding the boat and demonstrating its movements.

The team presentations featured playful narrative details, such as the Ferris Wheel Team's description of their client as one who "likes fast and spinny rides that are scary and would be life threatening", or the Boat Maze Team's opening statement, "First, we want to thank our sponsor, Bob industries, made by Bob, who is this guy". At the same time, each team's presentation included examples of problem solving in an engineering context. For example, the Ferris Wheel team said, "it has an unstable base that's why we used some tape," and mentioned that they would use nails instead of tape for the real ride. The Boat Maze team was also aware of the role that constraints played in their creation. They said "we didn't have the materials or the time to do that so . . . we could only make the upper floor." They also included this on the list of prioritized features for their design on a planning sheet (Figure 2c). Our research methodology was not rigorous enough to speculate if the game directly influenced the engineering thinking observed, but it was clear that the game allowed for detailed discussions of engineering concepts, and that all groups touched upon these in their presentations.

V. Conclusions and Future Development

We are optimistic about the game's potential to effectively scaffold engineering design content knowledge during project based learning activities. Each student who participated in the study was able to successfully design, prototype, and present a solution to the challenge within the two hour session. Although the facilitator in the case study is not a perfect stand-in for the intended end-user (e.g., teacher), we believe that little technical background knowledge of engineering design is required of the facilitator. The game discretizes the engineering design process in a way that encourages formation of easily scaffolded mental models.

Our next step in evaluating the game is to follow a more rigorous design based research methodology[11]. This includes testing in classrooms with in-service teachers, using additional methodologies such as interviews and surveys to evaluate effectiveness, and keeping game developers and researchers at a distance from the game players when the game is in use. In order to achieve a wider dissemination of the tool for testing, we have begun developing a web based version and a formalized script for facilitators who are new to the game.

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