NEXT GENERATION ME 250 GAME

Frontier Frenzy

Sponsor: Michael Umbriac, Lecturer IV, University of Michigan Department of Mechanical Engineering

Professor Daly - ME 450 Winter 2024, Section 2, 4/29/24

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Executive Summary

ME250 (Design and Manufacturing I) at the University of Michigan is the first course Mechanical Engineering students take in order to learn about introductory engineering principles, such as engineering design process, basic analysis and application of machine elements, hands-on experience with CAD systems, and prototyping. Over the last few semesters, students have learned the most efficient strategy to play the current game and have produced progressively less creative robot machine player (RMP) designs. To address this, Prof. Mike Umbraic has requested a new game for Fall 2024 with a mostly manufactured field and a written game manual to explain how the game is played and scored.

Key constraints, stakeholder requirements, and engineering specifications are determined by engaging with our sponsor and key stakeholders such as past students. The game should be conducive to teaching linear and rotational motion, encourage machining, and should require collaboration between robots to earn points in the game. The field must be no larger than 10 x 9', have an easily transportable game board, playable by 3-4 RMPs, and the field must be reasonably manufacturable. Finally, the game must have at least 3 thematically related tasks, scores must be objectively calculated at the end of the game, and the game board can withstand 3 years of use in the classroom. After the conclusion of engaging with multiple groups of stakeholders, brainstorming, and the use of a problem-oriented design process, a Western theme was selected as the alpha design, and ultimately the final design. This game has 8 tasks: The Mountain, Clear the Fumes, Track Builder, the Maze, Parking, Robbers, Horse Wranglin', and Hang your Hat. This game was selected due to its high score on a Pugh chart that contained the requirements and specifications. This meant that the Western game most aligned with the important features the game needed to have such as a collaboration task and fitting into the correct size.

In order to verify that the selected tasks and game theme met the requirements and specifications, the game was built in CAD, which allowed for visual inspection to test for things like size limits and the need for rotational motion. Low-fidelity prototypes were built for tasks such as the robber in order to test functionality, and high-fidelity prototypes were built and tested for other tasks such as the hats in order to make sure they were playable with linear and rotational motion by an RMP. For many tasks, first principles analysis such as force diagramming was used to make sure tasks like the mountain could withstand the weight of RMPs. The game created meets all of the requirements and specifications outlined by our sponsor and wanted by past students. At the conclusion of this project, the cost has been $1550, which is less than the $1700 budget. The final field has been mostly assembled using 2 ping pong tables, lots of two-by-fours, plywood, plexiglass, and PLA. Materials were cut in the Mechanical engineering machine shop and screwed together using screws and a drill. Validation for this game has begun, but will mostly occur once students are in the classroom playing the game and developing new RMPs specifically designed for the game.

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Introduction:

In order to graduate with a Mechanical Engineering degree from the University of Michigan, students must take 5 lab and manufacturing courses. These courses are designed to teach students about engineering through hands-on learning and to encourage problem-solving by teaching students how to solve problems systematically. ME 250 (Design and Manufacturing 1) is the first course in this series. In this course, students learn the basics of first principles analysis, a problem-solving technique that requires you to break down a complex problem into its most basic and foundational elements, and apply concepts learned in other courses such as force diagramming and load distribution through gameplay. Each semester students are presented with a challenge in the form of a game and asked to build an RMP (robot machine player) that will accomplish the tasks offered in that game.

For the last six semesters, the game played was called Space Race [1]. In Space Race, students are tasked with collecting aliens (cubes) and scoring them in one of two scoring zones. One zone is a basket that is easily accessible and the other is the rocket which must be opened by another RMP on the field to be used for doubling points. In order to lower the lever to open the rocket, a weighted block must first be moved out of the way. To acquire aliens, RMPs can collect them from the ground or collect them from elevated posts located around the field. RMPs can also turn on stars (light switches) or move a flag from one corner of the field to another. All of these tasks are completed in order to earn as many points as possible for each group's lab section and to win the game at the end of the semester. The Space Race field can be seen in Figure 1 below.

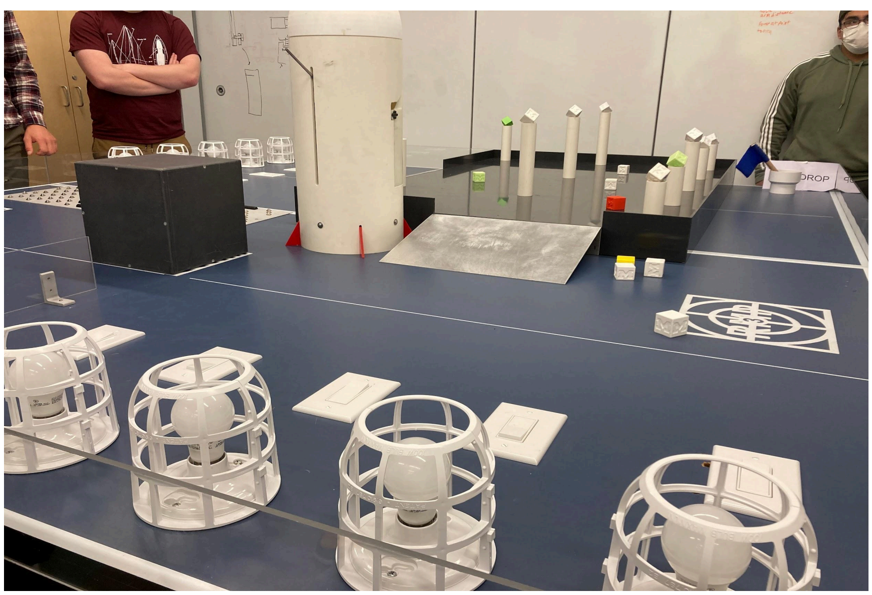


Figure 1. This image shows the current ME 250 Space Race game and its field. In the bottom front of the image, there are the stars (light switches) and top left there is the asteroid and the

rocket. Towards the top right, it is possible to see the different alien cubes and the posts that they are stored on.

In the last three semesters, there has been a lack of originality in RMP designs as there are only so many different strategies to employ, and teams were able to learn from previous RMPs. Our sponsor, Professor Mike Umbriac, has requested that our team design and manufacture a new playing field and game manual for ME 250. For Manufacting the team has been asked to get as far as possible with the expectation that the University of Michigan Mechanical Engineering machine shop will finish some tasks such as wiring. The motivation for this project is to make a game field and manual that allows for original problem-solving using principles taught in ME 250 [i.e. CAD, subtractive machining, first-principles analysis, empirical data collection and analysis, transmissions, motors, engineering drawings, testing and building, etc].

The fundamental problem this project is trying to solve is to create an entirely new game that compliments the hands-on experience of ME250 by introducing students to the mechanical engineering process of designing, testing, and building. The deliverables include a completed game field design and mostly built field as well as a written game manual explaining how the game is played. By introducing a novel game theme and game tasks that are different from past games, students are encouraged to engage with new concepts and design solutions. A critical focus of the project is designing tasks that test both linear and rotational motions, and promote collaborative problem-solving strategies among participating teams within a ME250 lab group. A successful 250 project would be one that meets all of the constraints (such as specified budget and resources for the ME250 students as detailed in the game manual). A successful project would also meet all our ME450 project's engineering specifications based on stakeholder requirements (such as linear and rotational motions, team collaboration, different game theme and tasks from past games, field dimensions, ease of score calculations, written game manual, etc). For this project, the constraints are that we must spend less than $1,700 on the field and the game must be playable by three or four RMPs.

Benchmarking:

The benchmarking process started by looking at the previous course projects, namely three out of four of the most recent games (the asynchronous COVID game was ignored). These games all have fields, manuals, and past student work that is useful in seeing what is successful and what could be improved. After looking at what had previously been done by the sponsor, outside organizations that created games for robots were also reviewed in the benchmarking process; this meant looking at courses at other universities and other robotics competitions.

In 2017, the game used in ME 250 was called Ninja Relay [2]. The goal of this game was to work with the other three RMPs in your section to pass a cube from zone to zone and score that cube in a basket without having any RMP leave the zone it was assigned to. This game meets the following requirements: RMP collaboration while using linear and rotational motion, and it is under the field size limit (about two ping pong tables). This game will not work for our problem because it is only playable with four RMPs, not the three RMPs as requested by our sponsor to address smaller class sizes. It also only has a single task, unlike our requirement of multiple tasks with varying difficulty. This also means that this game will not work for the ME 250 students because, when talking to our sponsor, past and upcoming students, many requested multiple tasks to work on.

Next in 2018, the class moved to Game of Zones [3] which was very similar to the Ninja Relay. This game had a similar objective of moving a cube in collaboration with the other RMPs in your section to score them in a basket. Game of Zones was slightly different because RMPs could score cubes in their own zones as well. This worked for what our sponsor requested our game include because there were multiple tasks that could be accomplished, and they had slight differences in difficulty levels. The varying difficulty levels for tasks was an improvement from the previous game that we uncovered during stakeholder interviews as part of the project, so we want to make sure it is included [4-5,14-17]. This game did not work for color-blind students because it used color-coded blocks and we want to make sure our blocks/scoring items are inclusive to those who are color-blind. This game is also not playable by 3 RMPs, which our sponsor has required the game we designed to be.

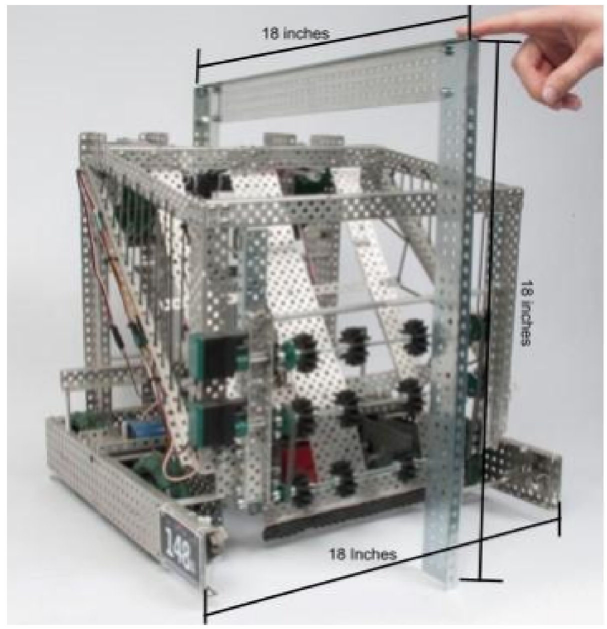
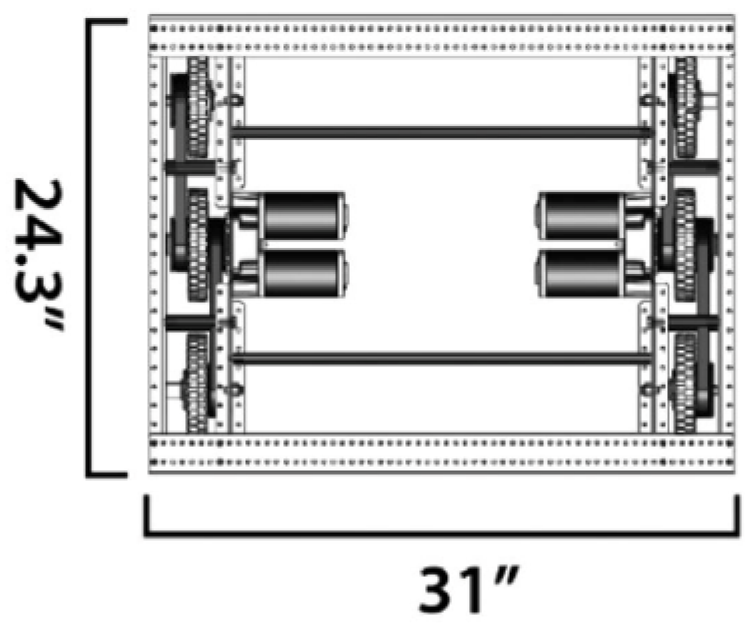
The current game is Space Race [1]. This game worked for our project team and what our sponsor would like the new game to look like because it was able to be scored at the end of the game and because the tasks had varying difficulty. This game is also playable by 3 or 4 RMPs which our game will need to be as well. Despite how well this game worked in past semesters, this game did not have a lot of opportunity for collaboration between RMPs and it was hard for color-blind students to play due to colored tasks. These colored tasks impact our stakeholders with color-blindness disabilities because it makes the game not playable for everyone, and it does not give teams the chance to work together. To this end, we are incorporating design elements that are easily distinguishable without reliance on color, and we are creating tasks that encourage or require cooperative strategies among RMPs.

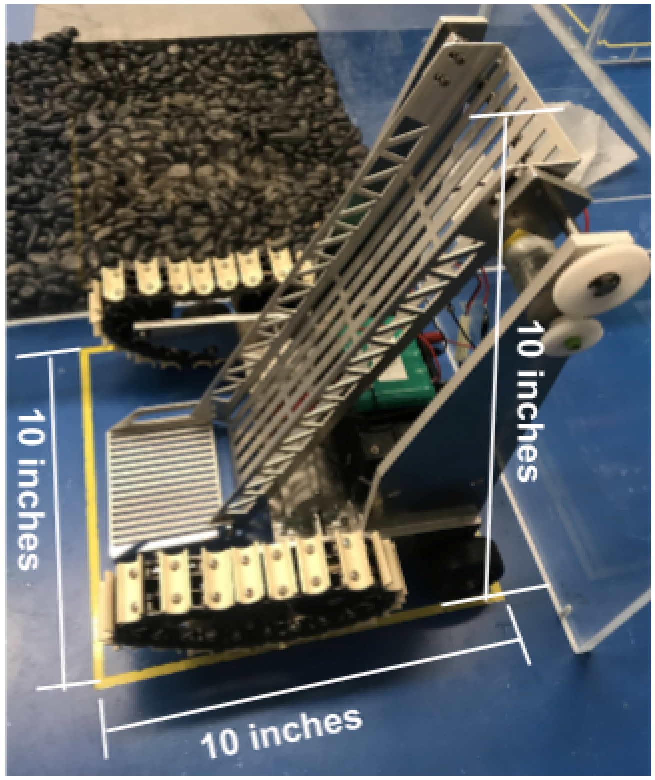
The first outside source we looked at for benchmarking was the First Robotics Competition [6]. We chose to look at the first robotics competition because many high schools use this as an option to teach students about STEM principles and engineering [7]. This competition worked for our project team to look through because it is the same kind of idea where students are given a game and told to solve the problem from problem definition to final design. It also works for the ME 250 course structure because it relies heavily on students' machining, using linear and rotational motion, and doing testing and iteration. First Robotics also takes place in a similar amount of time as the ME 250 students will have, about 14 weeks. This game does not work for our problem or the ME 250 facility because the playing field is too large at 27 ft by 54 ft compared to the 10 ft by 9 ft limit the ME 250 game has. It also does not work for ME 250 students because students in FRC spend over $6,000 on their robot whereas ME 250 students only have $50 to use. This budget is mainly impacted by the fact that FRC robots are much larger than the 10”x10”x12” ME 250 RMPs, weighing over 150 lbs. ME 250 also has teams of about 5 students whereas FRC robots utilize teams of 15+ students. We utilized the different possible tasks (especially the ones incorporating linear and rotational motions) and team collaboration strategies from this benchmark during our ideation process.

Vex Robotics [8] is another similar robotics program that middle and high schools use to teach students about STEM principles. It works for the ME 250 facility and the project sponsor because it is a similarly sized field with a similarly scaled game in terms of time, point distribution, and tasks for gameplay. It also works because the robots require linear and rotational motion, and the game focuses heavily on engineering principles and the ability to explain your design process. One of the main components of the game is a judge's interview where students need to explain their methods and engineering notebooks. Despite this, Vex will not work for ME 250 students as it is because their season is too long (6-12 months), and the game requires you to build a robot out of pre-manufactured pieces. This benchmark helped us with exploring tasks that require linear and rotational motions, and game themes and different team collaboration strategies. This has led to the conclusion that neither Vex nor First could be adopted for this course because neither challenge meets all of the stakeholder requirements.

Our last benchmarking source is Intro to Manual Machining offered at Carnegie Mellon [9]. In this course, students learn all about different types of subtractive manufacturing through the use of lathes, mills, CNCs, and more. However, this lacks a game competition, which is the main goal of this project. We identified the following gaps in this benchmark that need addressing: team collaboration, linear and rotational motions, mechanical engineering design, testing, and building process, etc. Table 1 shows images of the approximate size difference between the robots that are built for FIRST Robotics, Vex Robotics, and ME250. The robots needed for the first and Vex Robotics games are much larger than the ones ME250 students would be able to build with the supplies they are given, which is a constraint we need to consider in designing our version of the ME250 game.

Table 1. Robots Comparisons for Different Competitions

Event	Robot
Vex Robotics	
FIRST	

ME 250	

Stakeholder analysis:

The team considered stakeholders of many types. As shown in Figure 2, stakeholders were classified in terms of direct impact on the project and how they are affected by the project.

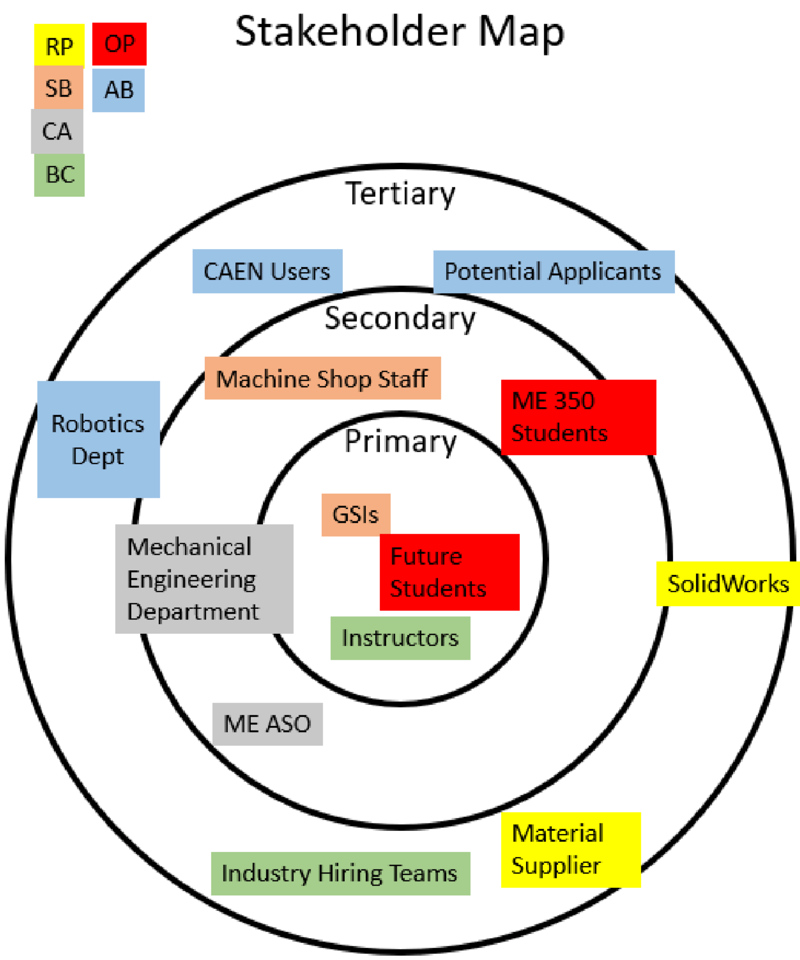


Figure 2. Stakeholder map showing the primary, secondary, and tertiary stakeholders. All of the stakeholders are also categorized as: Resource Providers [RP], Beneficiaries of the Status Quo [SB], Complimentary Organizations [CA], Beneficiaries and Customers of the Project [BC], Opponents and Problem Makers [OP], and Affected/Influential Bystanders [AB]

The main stakeholders who are affected positively by our project are: the instructional team for ME 250, the Mechanical Engineering department, the ME ASO, and future industry HR teams that hire these 250 students. The team considered these groups the main stakeholders since all of these stakeholders benefit from keeping the mechanical curriculum fresh and challenging, which creates an environment that pushes the budding engineers [the 250 students] to delve into the creative design process, without using the crutch of previous semesters' projects and ideas. The team also believes that the Robotics Department has the ability to be affected positively by this project since it has the potential to encourage more people to declare robotics as their major if they really enjoy creating and designing their RMPs.

The stakeholders that might be affected negatively are ME350 and 450 students, CAEN users, and the machine shop staff. ME350 and 450 students already have to compete with ME 250 students for resources like the machine shop and CAEN computers, which will also affect other CAEN users negatively. With a new project, the engineering drawings that the machine shop staff will be receiving and approving are going to be different from what they have seen in previous semesters. This means it will take them some more time to learn what to expect to see, give better, quicker recommendations for it, and be able to understand/practice machining these common design elements that the RMPs develop to solve the same problem. This takes the machine techs, and the machines in the shop, away from the 350 and 450 students as well.

This project also has a few societal impacts. One societal impact is to introduce future mechanical engineers to the world of the engineering design process for projects. They get an application to put lectures into use and learn important skills such as CAD, engineering drawings, and subtractive and additive machining. If the project is engaging and fulfilling, it can inspire these budding engineers to continue down this path, and eventually make huge contributions to the world, all from a fun way of learning and applying the fundamentals. The largest social impact, however, as emphasized by our sponsor, is education, as this project is for a class he is teaching at the University of Michigan. Since this is a foundational course that is meant to form the bedrock for future engineers, the application of the content they learn is critical to building connections from lecture to the real world; this will allow students to better grasp important engineering concepts that have implications in the real world of engineering after college. Therefore, the goal of the project is to intertwine it with the lesson plans and the learning goals he has for the course.

As this course is for educational purposes, it is important to make sure that everyone has access to the same educational benefits. For stakeholders who are colorblind or who use a wheelchair, not considering them when building would mean they might not be able to interact with the game and would not receive the same educational benefits as others. For these two marginalized groups, the choice of colors and maximum game object height could be large factors in how these students approach the game and what they will do to solve it. For example, the team worked to make game objects that can be viewed differently by having both different shapes and colors to allow a colorblind person to distinguish them. Another example is having no field object larger than the viewing sight of an average person in a wheelchair. If the created game was inaccessible, there could be an unintended consequence of discouraging people with these disabilities from becoming engineers.

Profit plays no part in this since nothing is going to be sold, rather money will be spent by the department to procure the materials needed for the RMP kits.

The environmental impact concern our sponsor has is also fairly low. However, one of the larger environmental impacts that this project created is waste. In order to mitigate waste, the team tried to use materials that were purchased for previous games or previous ME 450 project scraps before buying anything new. We also chose materials that were recyclable such as wood whenever possible. On the board, about 25% of the materials were second-hand or leftover materials and about 75% of materials are recyclable without special systems. This also helped to keep the team well below the budget of $1700.

All of these considerations worked towards our main goal of creating an engaging game that gets young engineers captivated by the creative design process integral to many aspects of engineering.

Intellectual property:

For this project, intellectual property was handed over to the University of Michigan and did not stop ideas from being considered. As we did not take any tasks from a copyrighted game (such as a Vex or FIRST game) there were no complications that arose around being able to use an idea. No names, copyrighted characters or franchises were used. Ideas that were considered were only generic ideas such as " Western" or " Deep Sea" which are too generic to allow anyone to own a trademark on them. There was also no need for IP protections on this project; the end result has one user, which is the ME 250 course at Michigan. The University of Michigan owns the intellectual property that was created by designing this game.

Design Process:

This project was completed following a more problem-oriented design process, which is based on the ME450 Design process model. Before committing to a solution, background information was explored in order to create encompassing requirements and specifications, while gathering as much data as possible. From there concepts were generated using brainstorming and mind mapping. A design was selected using a pugh chart and the final design was tested using a wide variety of empirical, computation, and theoretical testing. Because of time limitations, the team used parallel prototyping for multiple concepts selected from the concept generation stage. This was a better use of resources at the team's disposal, as opposed to a solution-based model, like the March model [21] that would require much more time to bring multiple ideas to fruition individually, before iterating again.

For the context of this project, a problem-oriented design process model with a combination of stage-activity-based approaches is the most useful. The user requirements and engineering specifications need a thorough analysis of the problem structure before generating solutions. However, we feel that an extremely linear process, similar to the Dym and Little model [22], would require too much time to be spent on each section before being able to move on. Thus, some re-interactivity and the ability to go back to previous sections is important. For this reason, the team followed the ME 450 design process [12]. To that end, this team spent a lot of time in problem definition and design solution development and verification. The project has now been completed through the testing phase and is fully in the building stage. As much as was expected to be built has been built and the project has been handed to the machine shop with the last few parts to finish, and the manufacturing plans. Figure 3 demonstrates this modified version of the ME450 model.

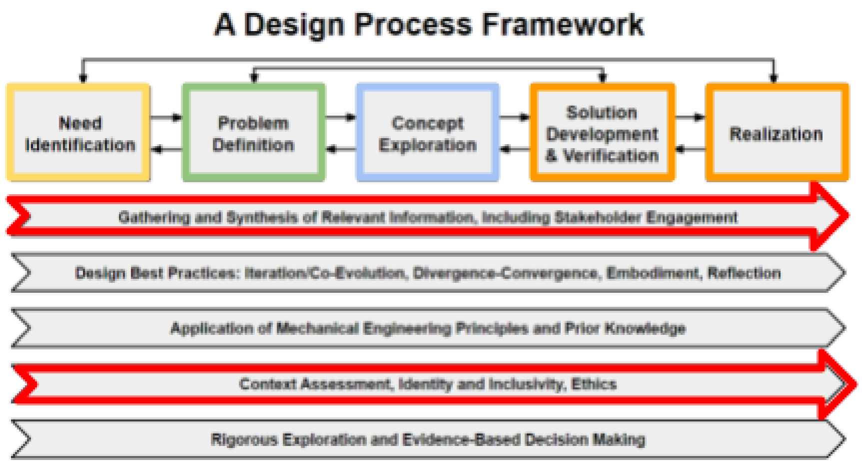


Figure 3. The ME 450 design process model, with certain areas emphasized. The areas highlighted in red are areas where the team has placed a larger focus and spent more time. The areas in blue are spots where we minimize time spent, trying to be as efficient as possible to be able to move on and spend time on the areas in orange, which are typically outside of the 450 curriculum. The area in yellow represents a spot where there was not too much time spent since the need identification was done for us by our sponsor, and finally, the green highlight shows an area where the team spent a lot of time that turned into a checkpoint and once completed did not require too much more time going back.

Information Sources:

For this project, many of our stakeholders are also our information sources. One of our largest information sources is Professor Mike Umbriac and the instructional team for ME 250. Mike is the main instructor and is the one providing information on what teaching goals the game should accomplish. His information comes in the form of interviews once every two weeks throughout the semester and frequent emails. Another main source of information for this project is interviews with past ME 250 students. Their insight into how the game has been played, what worked, what did not work, and what they took away from class will highly impact the design of the game for future ME 250 students Another main source of information is past ME 250 game manuals and documentation such as the kit of parts. These sources of information will give input on how to structure the new manual and provide a framework for a game that students can reasonably design a successful RMP to play.

This project does involve the use of a few standards. The first standard that was deemed important was the NCEES Engineering Education Standard [10]. This standard is important because it outlines what must be taught in engineering design courses for a university to have an accredited engineering program. This game will meet the standards needed for having a building/constructing aspect of an engineering course. We need to stay within this standard in order to keep ME 250 as a class that the University of Michigan is allowed to offer for credit. Another important standard is the Ann Arbor City Fire Code [11]. When building a table and a field, it is important the field itself is not too large so that the class can stay in its current room and meet fire regulations. This was accomplished.

We did not engage with the librarian as the few standards we needed were able to be obtained using the University of Michigan Mechanical Engineering library website. Talking with our stakeholders was our best information obtaining method, and also led to our most challenging aspects of making sure that recorded responses represented a wide range of stakeholders.

Requirements and Engineering Specifications:

Our requirements and engineering specifications are listed in Table 2 below:

Table 2. Engineering Specifications and Requirements

#	Stakeholder Requirements	Engineering Specifications	Importance (1-10)	Verification
1	Must have field dimensions that fit current storage [1,12-13]	- Fully opened field area no larger than 10 feet X 9 feet	10	-Planned elements are spaced in CAD within the size limits and checked using visual inspection of the CAD model.
2	Team collaboration requires two different RMPs to interact [4,13]	- At least 1 game task that requires two or more RMPs to interact with each other during the game [directly or indirectly] to complete the task	10	- At least 1 task that has concurrent components physically too far or blocked by obstacles for one RMP to complete alone i.e. review of the task list description.

3	Scores are easy to calculate [1,12]	- All tasks have a scoring mechanism that can be counted at the end - 8 ≥ x ≥ 6 tasks to be scored - Less than 2 minutes to count the score at the end of a round.	10	-Each task can be counted in <30 seconds by 3 randomly asked ME250 GSIs or instructors. -Each task has no more than 10 game elements to count for the total score.
4	The game requires students to use linear or Rotary motion to accomplish a task [1,14]	- At least 1 task that requires linear or rotary motion to score points.	10	- Test game functions requiring specific motions with prior years' RMPs, where applicable - A visual inspection of the concept to determine how many tasks require an RMP to use a lever, pulley, or rack to operate
5	Must use different point distributions for scoring `tasks [1,15]	- Need at least 2 levels of difficulty depending on the time it takes to complete	10	- Count the difficulty levels of tasks - Define the difficulty criteria based on the time required to complete each task and assign the difficulty levels.
6	The complexity and time to manufacture game elements need to be reasonable [12]	- A part must be manufacturable using a basic lathe or mill under 1 hour by a 4th year ME student - A part must be manufacturable using available 3D printers under 12 hours - Manufacturing part materials must be readily	10	- Confirm each part manufacturing process complies with specified limitations through process charts, engineering drawings, CAD/CAM files, setup sheet evaluations, and feedback from machine shop personnel

		available at the machine shop		
7	The playing field needs to be inclusive and viewable to students with height limitations [1-3,15-18]	- The top of the playing field must be under 6.5 feet tall	9	-Validate height in CAD before manufacturing - Visual inspection of the sketch with dimensions noted. - Measure/design that all tasks are under 6.5ft
8	The colors and shapes of the game elements must be suitable for players with color blindness.	- All game elements must be distinguishable in at least 2 ways (ie shape and color)	9	- A visual inspection of the colors and shapes of the game elements.
9	The playing field will be set up in 15 minutes and have wheels for transportation. [1,12]	- Instructors can set up the main playing field in 15 minutes. - Less than 5 minutes to move the field 100 meters on attached wheels. - A single game element should not exceed 20 lbs. - Instructors can setup all playing field elements (Mountain, hats, tracks, blocks/cubes, bucket) in 20 minutes	8	- Group members test and count the time - Estimate time for setting up the playing field and each field element based on the complexity of the game elements.
10	There need to be novel tasks [1-3, 12]	- At least 2 tasks that are completed in a different manner than the previous three ME 250 games	7	- Compare tasks to those mentioned in previous ME 250 manuals and videos

11	The game must be playable within a short period of time. [1,12-13]	- Each round of the game cannot exceed 10 minutes	5	- Test the completion time of various game functions using past years' RMP to see if this time restriction is reasonable, where applicable - Estimate how long each task would take to complete and find the total time using past RMPs average movement speed. - Estimate how many tasks can be completed within the time limit using Past RMP's average movement speed.
12	The playing field/Materials used to build field elements need to be durable [1-3]	- > 3 years and can withstand >1000 rubber-wood and aluminum-wood interactions - Playing Field materials can support > 100 lbs	5	- Manufacturers and Suppliers provided durability specs for components. Use the lowest durability for components - Engineering analytical analysis using FEA - Conduct experimental analysis including measuring the force that each game element can hold.
13	There needs to be a compelling storyline to provide a task and purpose to students. [13-15]	- At least 3 tasks must be thematically related	5	- Read through the game tasks to see if they match the theme.

We initiated the formulation of specific requirements and constraints for our project through structured discussions with our sponsors. Subsequently, to refine these preliminary guidelines, we employed a qualitative research methodology by conducting face-to-face interviews. This research phase targeted individuals who had previously enrolled in the ME 250 course, aiming to extract their preferences and criticisms regarding the gameplay experiences they encountered. We interviewed approximately 20 students who have taken ME250, as well as 3 ME250 GSIs, to ask them about their likes and dislikes regarding the Space Race game currently being used in ME250, their level of interest in the theme, and some game elements they hope to see. Regarding the aspects they liked, Space Race features a variety of tasks for them to choose from and includes tasks that require teamwork, resulting in our requirements including the necessity for games that involve teamwork and the need for new games. Regarding the least liked aspect, some tasks occupy a large portion of the score during the game, making these tasks overly important and causing teams that are unable to complete these tasks to lose the possibility of achieving high game scores directly. Therefore, based on this feedback in designing the requirements, we stated the requirement for a reasonable distribution of task difficulties and corresponding scores that match the difficulty of balancing the game. This is to ensure that players do not lose their competitive edge simply because they are unable to complete a specific task. Such firsthand insights are invaluable for enhancing the relevance and engagement of our proposed game design as their opinions can help me identify what improvements we need to accomplish. In an effort to incorporate inclusive design principles, we also engaged with one student with a physical disability who had participated in ME 250. Since this individual we interviewed had participated in the ME250 game while in a wheelchair, we also included this individual's feedback on aspects of the game that needed improvement, which led to requirements in the design of the field's height. After concluding that the ADA specification for reaching height was infeasible [22] due to the height of the ping pong tables, it was decided to focus on viewing height. After conducting some brief experiments, it was determined that the max reach height for most students was shorter than the max viewing height. Because of this, we have the maximum height for field elements set to 6.5". Considering students with color blindness, restrictions and requirements in the differentiation of game elements have been applied to the color and shape of game elements to ensure that they can distinguish. These interactions were crucial for gathering comprehensive feedback to ensure that our game design accommodates the needs of individuals with physical disabilities, promoting equal participation opportunities. Finally, as part of our iterative design and evaluation process, we plan to deploy a quantitative feedback mechanism through electronic surveys directed at the current cohort of ME 250 students. This phase aimed to quantify the students' perceptions and attitudes towards the game, both before and following an introduction to its objectives and mechanics. The collected data informed subsequent refinements to ensure that the educational game aligns with the learning outcomes and engagement criteria of the ME 250 course.

To prioritize our project requirements effectively, we developed a structured approach that includes analyzing stakeholder needs, evaluating our technical capabilities and limitations, and assessing potential risks. First, we closely examine the expectations and needs of the primary stakeholders involved with our project which includes project sponsors, previous ME 250 students, and instructors. We aim to align our project with the diverse needs of these stakeholders to achieve widespread acceptance as the importance of requirements largely depends on the stakeholders' emphasis on particular requirements. For example, our sponsor emphasized the importance of the field being easy to transport and set up, which does not contradict other stakeholders' needs. Therefore, we marked it as an important requirement. Next, we assessed our technical feasibility by looking at our current technological skills, what our project can do, and any limitations we might face due to budget, time, or resources. We focused on requirements that fit within these constraints to keep our project realistic and achievable. Risk analysis is another crucial step, where we look at the potential challenges each requirement might bring, including the risk of not meeting our project's goals. We paid special attention to high-risk areas to either address them early or reassess their value to our project and plan to prepare some contingency plans to address some of the anticipated challenges in case we are unable to complete tasks as expected. For the team collaboration requirement, we emphasized the need to avoid the risk of cooperative games being completed individually in design, ensuring that collaboration is essential to accomplishing the task. Finally, we evaluated the impact of each requirement on our successful completion of the project. For example, some requirements, if not met, could lead to the failure of the entire project, and such requirements are considered to be important. For our field dimension requirements, if the designed game space exceeds the size of two ping-pong tables, it cannot be accommodated in the ME 250 experimental laboratory, preventing it from being showcased to ME 250 students. Failure to meet the dimension requirement would result in the failure of the entire project and we assess this requirement as critical.

There are six essential requirements: 1. The field dimensions must fit the current storage space; 2. Team collaboration requires two different RMPs to interact; 3. Scores are easily calculated; 4. The game requires students to use linear motion to accomplish at least one task; 5. Must use different point distributions for scoring tasks; 6. Ease of Manufacturing Parts. For the first requirement, due to space constraints in the ME 250 lab room and storage room, the largest possible size for our game area is equivalent to two ping-pong tables put together, measuring 10 feet by 9 feet. We can have smaller playing fields, but they cannot exceed this size; otherwise, the lab room would not have enough space to accommodate the field, and it would also make the classroom too cramped for students to move freely. Secondly, the course is structured to compel lab sections to work together by strategizing each RMP's role in the section's game plan. Having at least one specific task that requires further collaboration helps to ensure students learn how to communicate across project teams. Furthermore, we need to ensure that the score associated with each game task can be counted at the end of the game. We aim to avoid any game that requires in-progress scorekeeping to prevent any disputes over scores. Then, as linear and rotational motion are core concepts of the teaching content, we need at least one game task that can be completed by an RMP doing either linear or circular motion. This will directly test whether students can apply the course content to their designs. Lastly, we aim for a relatively easy manufacturing process in the field so that we will be able to fix any potential problems within the time frame.

Following that, there are seven important (but not critical) requirements: 1. The game field must be viewable to students with height limitations; 2. The shapes and colors of game elements must be suitable for students with color blindness; 3. The setup and transportation of the game field should be easy; 4. New game tasks that are different kinds from the tasks in Space Race need to be introduced; 5. The game must be playable within a short period of time; 6. The playing field/materials used to build field elements need to be durable and finally; 7. There needs to be a compelling storyline to provide a task and purpose to students.

Considering the possibility of students in wheelchairs participating in the ME250 game, we aim to limit the entire game field's height to under 6.5 feet to ensure these students can also clearly see the entire game field for a better experience. For students with color blindness, our requirement is that game elements must be distinguishable in both shape and color to facilitate their differentiation. At the same time, considering that the game field needs to be moved from the ME250 lab room to an outdoor location for competitions, the ease of transport and setup becomes crucial. This mobility requirement leads to the requirement that instructors and GSIs must be able to set up the game field within 15 minutes, and individual game elements must not exceed 20 pounds. This ensures instructors can easily move these elements to set up the game field. Finally, as a new game, we hope to introduce at least two new game tasks to ensure the game's novelty and spark students' interest. The 5-minute game duration is based on the length of previous games and is not a strict limitation. The duration can be adjusted according to the specific game tasks and scoring, as long as it does not become excessively long (< 10 minutes). Additionally, storytelling potential gives us an estimation of how attractive the theme will be to the future ME 250 students. However, it would not be an influential factor when selecting the final theme. Lastly, the durability of the playing field is inherently very important because we want the game to last a significant amount of time. However, due to the low likelihood of testing this requirement and our belief that a reasonable selection of materials for the playing field and equipment can ensure it meets the minimum durability needs, we consider it not to be a particularly important requirement.

The aim is to ensure a comprehensive set of specifications that address all essential aspects. Each requirement has been carefully analyzed and translated into engineering specifications that guide the design and implementation processes. Additionally, thorough consideration has been given to identifying any other relevant engineering specifications that should be incorporated into the project, and, at this time, the team feels like all necessary specifications have been created.

For our project, these requirements are reasonable because they primarily focus on establishing a basic framework for our game field and the game itself. There are no specific guidelines on how to design the game or what specific game needs to be designed. This leaves us with a considerable amount of flexibility and creativity in our design process. Those requirements allow us to define the scope and limitations of the project while providing the freedom to innovate within those boundaries. A comparison of past games with the requirements and specifications can be seen in Table 3.

Table 3: A comparison chart between previous games and similar courses regarding specifications and requirements.

	Ninja Relay	Game of Zones	Space Race	First Robotics Competition	Vex Robotics
Must have field dimensions that fit current storage [1,12-13]	Yes	Yes	Yes	No	Yes
Team collaboration requires two different RMPs to interact [4,13]	Yes	Yes	No	Yes	Yes
Scores are easy to calculate [1,12]	Yes	Yes	Yes	Yes	Yes
The game requires students to use linear or Rotary motion to accomplish a task [1,14]	Yes	Yes	Yes	Yes	Yes
Must use different point distributions for scoring tasks [1,15]	No	No	Yes	No	Yes

The playing field needs to be inclusive and viewable to students with height limitations [1-3,15-18]	No	No	No	No	No
The colors and shapes of the game elements must be suitable for players with color blindness.	No	No	No	No	No
The playing field will be set up in 15 minutes and have wheels for transportation. [1,12]	Yes	Yes	Yes	No	No
There need to be novel tasks [1-3, 12]	No	No	Yes	No	Yes
The game must be playable within a short period of time. [1,12-13]	Yes	Yes	Yes	No	No

To better compare our designed game with previous games and similar outside games, we removed content from requirements and specifications that are not directly related to games, retaining only necessary aspects for comparison in the context of gaming. Compared to the three previously used games in ME250, our new design will place greater emphasis on the diversity of game task choices, ensuring participants have a sufficient variety of tasks to complete and adopting different scoring proportions to provide them with more strategic directions in designing game strategies. Additionally, we are also focusing more on accommodating students with physical limitations by incorporating height restrictions and designing game elements that differentiate based on both color and shape. Compared to other games or competitions in the outside world, due to differences in requirements, our designed game surpasses them in terms of both the size of the game field and the convenience of transporting and setting up the field. However, when designing specific tasks for the game, these competitions undoubtedly provide us with a lot of inspiration and ideas. In general, our game not only inherits the strengths of previous games but also focuses on rectifying and enhancing the shortcomings of previous ones.

Concept Generation:

The concept generation process for this project began with individual brainstorming, where each team member independently came up with 40 different ideas. Team members used tools such as morphological charts, mind mapping, storyboarding, and heuristic cards in order to generate more creative ideas. The main ideas fell into 3 broad categories which were later further refined. The 3 categories are tasks, field elements, and themes. Tasks are challenges that RMPs need to complete in order to earn points. There were 91 ideas initially for tasks. Notable examples include throwing rings at a target, moving blocks in a certain location, tipping over objects, dart throwing, the inventory of tasks, and a sliding puzzle task, etc. Field elements describe ideas that encompass large playing field items that do not necessarily have specific points or tasks associated with them, but they drastically change/affect the field layout. There were 20 ideas initially for field elements. Notable examples include having a maze, low-hanging obstacles, high obstacles, visually restrictive obstacles, etc. Themes are ideas that relate tasks and field elements into a broader story to provide task and purpose to the game while showing connections between the chosen game elements. There were 9 ideas initially for themes. Some notable ideas from these brainstorming sessions are Western, Fishing, Lego, Deep Sea, Carnival, etc. The reason why there were so few theme ideas is that more emphasis was placed on field elements and tasks since there needs to be many more of them and they affect the gameplay more than the theme. More select ideas can be seen in Appendix A.

After consolidating the 120 ideas, they were grouped into more specific categories: Collaborative tasks, linear motion tasks, rotational motion tasks, field elements, and themes. These categories were used to try and identify any gaps before moving on to collaborative brainwriting. One of the ideas produced from this session under theme/field elements was having the playing field be a chess board with pieces manufactured by the teams which the RMPs will have to move to accomplish tasks. Another solution from this session under field element was to have the playing field be able to fold, with slots for the tasks to go into to aid in the ease of transportation. After the brainwriting session, we held a second brainstorming session as a group in order to fill our largest gap, identified by our sponsor after a meeting: collaborative tasks. Five ideas culminating from these ideation sessions are:

1) Magic Piano
    a) This is similar to the FAO Schwarz piano, where an RMP will need to play notes in a specific order to then unlock a secret passage/tunnel where resources are located

Figure 4. Rough sketch of the magic piano combination lock idea, with the piano keys laid out

2) Ferris Wheel
   a) A Ferris wheel with many baskets is turned when an RMP drives over a button and stops when the RMP gets off. This is a collaborative task where one RMP uses linear motion to load the baskets of the Ferris wheel while it is stopped, and then the second RMP rotates the wheel to the next basket.

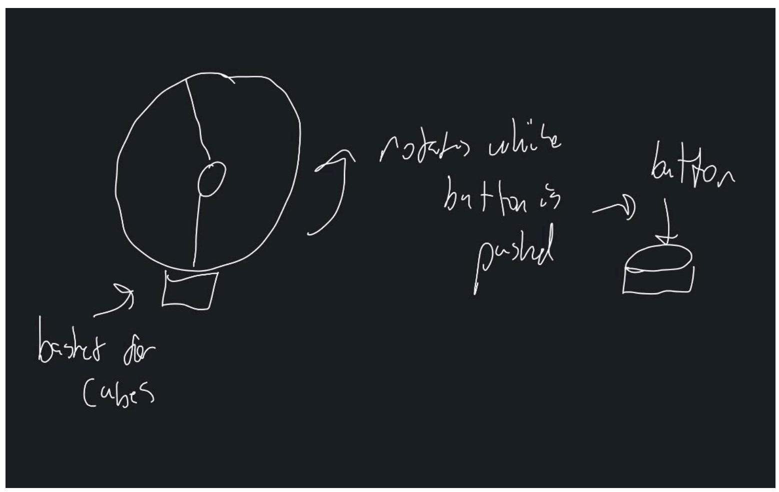


Figure 5. Rough sketch of the Ferris wheel idea, showing an RMP loading the baskets of the Ferris wheel, as well as the button used to turn it.

3) Park the Car
   a) There will be designated parking spots by the number assigned to each RMP. These parking spots will vary in difficulty, with some of them being flat and

others being on an incline. At the end of the game, all RMPs will need to be parked in these spots to earn points

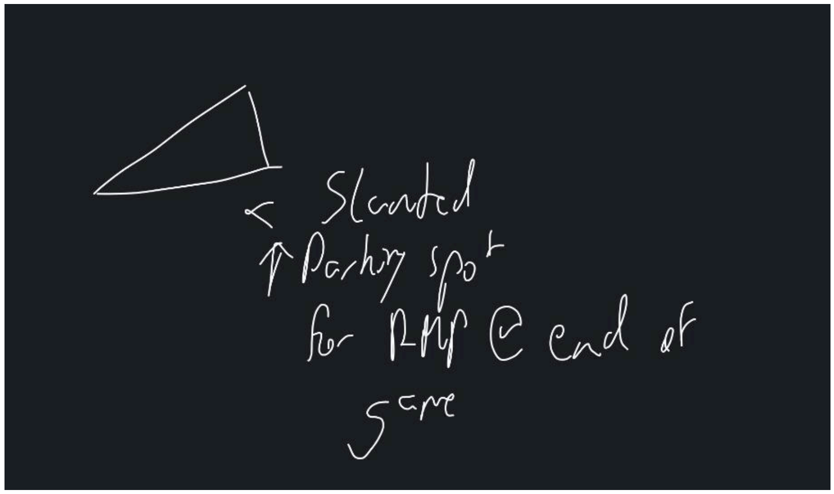


Figure 6. Rough sketch of parking the car, with an example of a sloped parking spot

4) Push the Turtle
    a) There will be a turtle that needs to be pushed from the beach to the safety of the sea [a marked zone]. This uses rotational motion since the RMP will need to push the turtle by moving with its wheels. Underneath the turtle, there will be a pit with baby turtles that also need to be rescued. This uses linear motion since the RMP will have to reach into the pit to gather these baby turtles to also transport to the Sea safe zone.

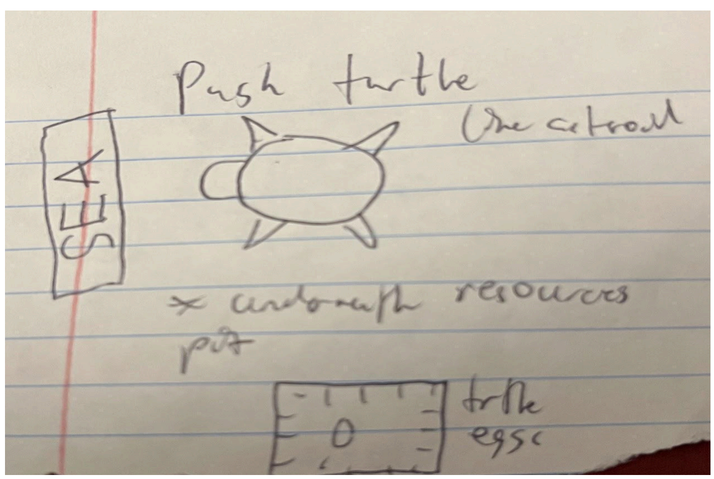


Figure 7. Rough sketch showing the turtle obstacle and the target “sea” zone with the resource pit underneath having turtle eggs

5) Jenga Tower

a) This will be a collaborative task that uses linear motion. RMPs will have to work together to build up a JENGA tower on the field, with bonus points for spelling words with the blocks with letters on them [i.e. having "apple" on the tower in the correct orientation].

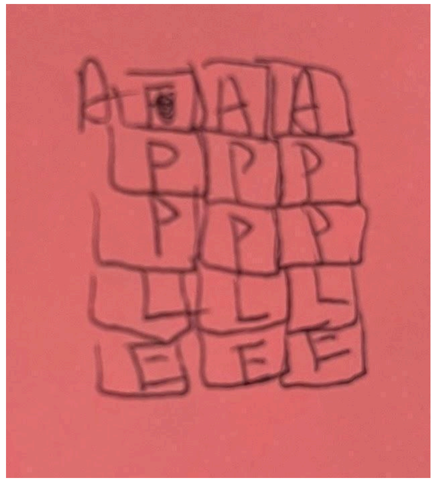


Figure 8. Rough sketch showing the JENGA Tower with the letters in the correct orientation

Concept Selection Process:

After generating over 140 ideas in total, the team set about combining and narrowing down these ideas into 3 distinct possible complete design concept solutions to present to stakeholders and gather feedback on what should be chosen to move forward into our alpha design. Each of the 3 complete design concept solutions had a unique theme with associated preliminary tasks and field elements ideas. Themes were selected first, and then their associated tasks and field elements were included based on how the tasks and field elements would relate to each other in the larger picture of the themes and their associated storylines. There were fewer themes than field elements or task ideas because the field element and tasks were more important than the overall theme, as seen in the requirements and engineering specification shown in Table 2. In order to narrow down 9 themes into 3 games that could then be decided between, each task and field element was assigned to the theme that was best associated with it. Most tasks and field elements were generated with a theme in mind, so assigning tasks to themes was relatively simple. From there it was possible to rank the 9 game ideas based on how many possible combinations could be made from the ideas, what would be feasible to build by a 4th year ME student and based on the resources we have, and which ideas students liked based on 20 interviews and in-class activity sessions. This ranking can be seen in Table 4 below. In order to narrow down these choices further, more student and sponsor interviews were conducted. Based on their responses to the ideas presented and tasks associated with the themes, we were able to gather important stakeholder input into the selection process.

Table 4. Nine Original Game Theme Ideas

Game Idea	Rank (1-9)	Idea Description
Western	1	Set in a western-time landscape, players navigate tasks like laying down "Build The Track" pieces for trains, "Clear The Fumes" with timely interventions, "Knock The Robber" figures of different stiffness, and "Hang Your Hat" on racks for points.
Carnival	2	A carnival theme with multiple different ride-based events to play. One could be a ferris wheel where you need to score an object into the 6 baskets. If you get all 6 you get a bonus.
Deep Sea	3	Field is consist of 4 layers including shore, beach, sea, and deep sea. Lot of sea animals featured in the game with associated game tasks.
Spelling	4	Spell the word. Make three cubes each marked with a letter. Three spots before each cube and push the block in the right order to spell the word correctly.
Football	5	Field is a mini football field. Tasks would include things like getting through blockers, and the game would have been more of an obstacle course/race between sections rather than just completing tasks
Pirates	6	The board would be sea and ship themed, and the RMPs would do tasks like firing cannonballs, raiding other ships, and slaying the kraken
Mines	7	This would be a mining theme, where RMs would have to extract valuable resources from a planet in order to earn points. There would be a mining pit as the central field element, with tasks like ore washing, save the canary, and building tunnels
Lego	8	Have a portion in the game that requires two RMPs to move pieces that that can stacked

		together to create a predetermined shape, if completed they get full time for that shape
Fishing	9	This theme was having the field be a small fishing town, and the tasks would be centered around running the town. There would be fishing tasks, as well as tasks that required RMPs to “clean” the water, and there would also be a boat building task

These three themes were selected: Western, Deep Sea, and Carnival. Then, we allocated a few additional tasks to bring the total number to six to eight game tasks to each theme based on their compatibility with the previously designed game tasks. For example, Western initially had 4 tasks as we see in table 4, and we added ‘Mountain’ and ‘horse’ tasks to have a total of 6 tasks. The selected themes and the list of game tasks are shown in the tables below along with the basic game field layouts:

Table 5. Western Theme with Selected Game Tasks

Western		
Task Name	Task Content	Requirements Accomplished
Build The Track	Two RMPs bring track pieces to the broken track and build.	#2, #3, #4, #5, #6, #8, #10, #12, #13, #14, #15, #16
Clear The Fumes	A countdown timer set for 2 minutes that ends the game if it runs out. A button needs to be pushed to reset.	
Knock The Robber	Pinball multiple robbers to push over different stiffness.	
Hang Your Hat	On the edge of the board, double sided hat rack. More points for outside placement.	
Horse Wrangling	Horses with varying heights need to have rings put on them.	
Conquer The Mountain	RMPs climb the mountain and finish certain tasks on the mountain.	

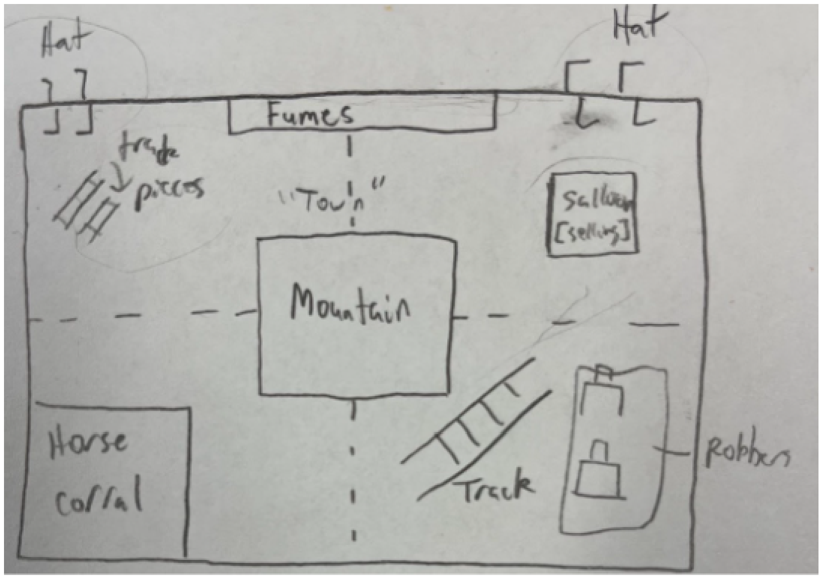


Figure 9. Field layout concept of the western theme, with the mountain object as the central item which roughly divides the rest of the field and other tasks into quadrants

Table 6: Deep Sea Theme with Selected Game Tasks

Deep Sea		
Task Name	Task Content	Requirements Accomplished
Push The Turtle	Move the turtle from the beach to the ocean.	#2, #3, #4, #5, #8, #12, #13, #14, #16
Sort Sea Animals	Move different sea animals to where they belong to.	
Lift object	Lift game elements to place on an elevated layer that RMPs cannot drive on.	
Chain Link	Attach chains to pull and move a boat that cannot be done by one RMP individually.	
Passing Objects Through A Wall	Pass game elements through a wall to another RMP to be scored.	
Field Maze	Maze the holes that must be traversed to get to the next scoring location.	

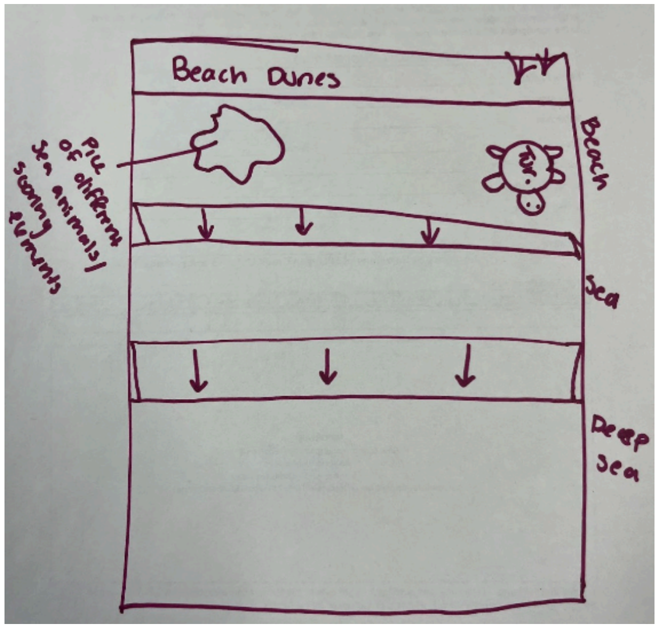


Figure 10. Field layout for the Deep Sea theme, which illustrates the main field feature of staggered levels with ramps navigating between the sections.

Table 7. Carnival Theme with Selected Game Tasks

Carnival		
Task Name	Task Content	Requirements Accomplished
Ferris Wheel	One RMP pushes the button to let the ferris wheel rotate and another RMP puts game elements in each cabinet.	#2, #3, #4, #5, #6, #7, #8, #12, #13, #14
Jenga Tower	RMPs play Jenga tower to make a pattern on the tower.	
Mario Flag Raising	RMPs put a flag on a standing bar.	
Soccer Shooting	One RMP pushes the button to open the fenced gate and another RMP kicks footballs into the gate.	
Game Element Passing	Each RMP carries a numbered game element that they must give to their RMP that has the same number.	
RMP Parking	RMPs park at the designated spots at the	

	end of the game.	

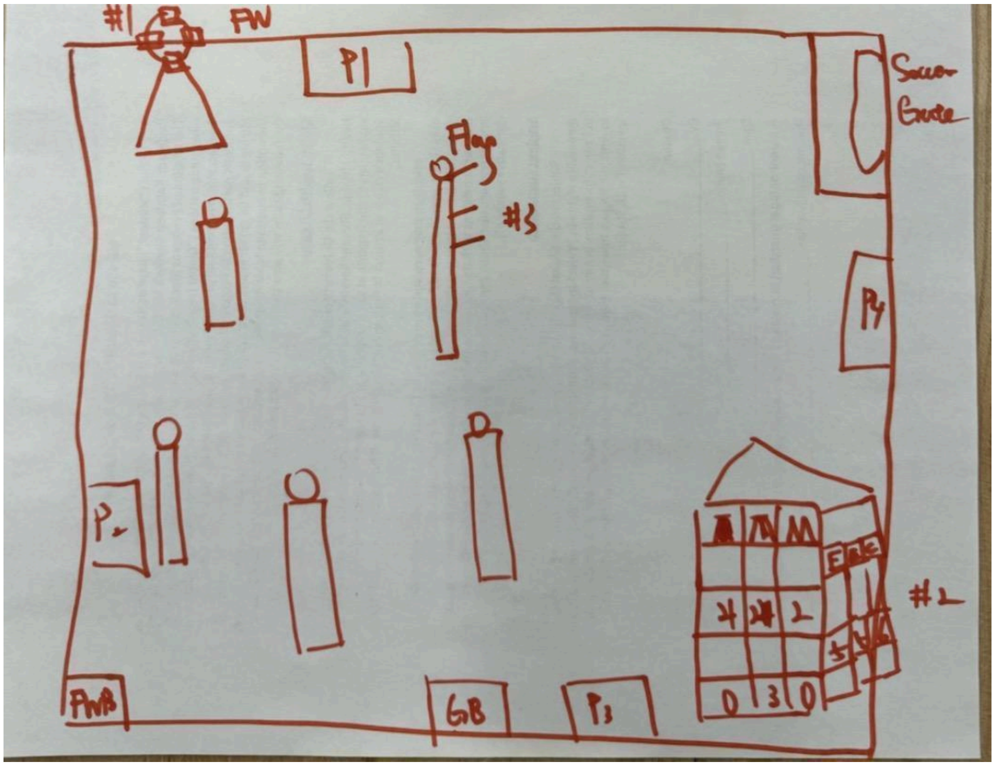


Figure 11. Field layout for the Carnival theme. The main field elements are the many flag poles for the hoist the flag task, as well as the layout of the parking spots for the RMPs.

As mentioned in Table 5, 6, and 7 above, each theme was assigned with six tasks and some tasks can be transferred into the other themes with slight adjustments to match the new themes. It was difficult for us to just choose one theme out of three selected themes as each theme accomplishes about the same number of requirements. Therefore, after selecting the top three themes and allocating tasks according to those themes, we chose to use a Pugh chart and use the current game, Space Race, as the baseline for comparison to decide on the theme for our final game design. Of the 13 reqs listed in Table 2, only 10 of these reqs are utilized as field dimensions, playing time, and durability reqs are going to stay the same regardless of the theme selected. We also combined height restriction and color-blindness inclusive reqs together in the Table 8 pugh chart. The Pugh Chart is shown below:

Table 8. Pugh Chart for Concept Selection

Requirements	Weight	Base: Space	Concept 1:	Concept 2:	Concept 3:

		Race	Western	Deep Sea	Carnival
Collaboration Opportunities	5	0	1	1	1
Ease of Setup and Transfer	4	0	0	-1	-1
Ease of Manufacturing Parts	4	0	0	-1	0
Height and color blind Inclusive	4	0	0	0	1
Novelty of Tasks	3	0	0	0	-1
Motion/Task Variety	3	0	1	1	0
Variety of Task Complexity	3	0	1	1	1
Ease of counting score	2	0	0	0	0
Storytelling Potential	1	0	0	0	-1
Total:	—	**0**	**11**	**3**	**4**

In our Pugh chart, collaboration opportunities were prioritized as the primary criterion with a weight of 5, in alignment with our sponsor's directive to foster direct interactions among RMPs. Unlike in Space Race where collaborative tasks could be accomplished individually through specific RMP designs, we assigned a uniform score of 1 to each of them, reflecting the focused intention to heavily incorporate and improve the collaborative tasks within those already assigned to the theme. Subsequently, criteria such as the ease of setup and transferability, the simplicity of manufacturing components, and inclusivity were each assigned a significance level of 4. The sponsor's criteria stressed the game's ease of setup and simple transferability of its components. However, the intricacy of the Deep Sea theme and the structural complexities of the Carnival theme's Ferris wheel and Jenga tower presented notable challenges in setup and transferability, resulting in a score of -1 for both themes in this aspect. Given the availability of pre-manufactured Jenga towers, only the Deep Sea theme received a -1 for manufacturing ease as we would have to manufacture all four layers by ourselves. Inclusivity was another evaluated aspect, with the Carnival theme scoring a 1 due to its flat layout, which offers improved accessibility and visibility for students in wheelchairs. Novelty of tasks was also a key consideration. We recognized both Western and Deep Sea themes as being on par with Space Race in terms of creative appeal, as evidenced by significant interest from our peers. However, the Carnival theme was perceived to be less engaging, reflecting a lower level of interest among our audience.

Furthermore, we assigned a significance level of 3 to both the diversity of motion tasks and the variety of task complexity. Our objective was to ensure that the selected theme would challenge the RMPs with a range of motions, including linear, circular, and vertical movements. Additionally, we aimed for a spectrum of task complexities within the theme, allowing students to achieve some level of scoring regardless of their skill level and to formulate their game strategies based on the difficulty and point distribution of each task. In this evaluation, both the Western and Deep Sea themes scored a 1 for meeting each of these requirements effectively. Less critical criteria included the ease of score calculation and the potential for storytelling. These factors were considered, but with lesser weight, in our comprehensive evaluation.

Upon aggregating the scores across all evaluated criteria, the Western theme emerged as the clear leader with a total of 11 points, underscoring its strong alignment with our objectives and requirements. The Deep Sea theme, while compelling in certain aspects, accumulated a total of 3 points, reflecting its limitations in comparison to the other themes. The Carnival theme, despite its unique challenges, secured 4 points, positioning it between the Western and Deep Sea themes in terms of overall suitability. Therefore, Western is the final theme selected that is consistent with the engineering specifications and sponsor requirements.

Although Western emerges as the superior design in the aforementioned Pugh chart, our calculations show that it also requires a budget exceeding that of other themes. Nevertheless, it still falls within our budget range. However, should we opt for optimization or modifications, we won't have as much surplus budget.

The first several solution concepts that occurred to our team were nine different themes each team member thought about, plus a whole bunch of other tasks that we imagined our previous RMPs completing. Compared with the Western theme, and the tasks and field elements that we thought of later in the process, those concepts were just initial thoughts without in-depth exploration of the possibilities and their merits or drawbacks. The main purpose was to give team members the right to make informed choices by providing them with ample options when selecting the final solution concept. There is no evidence of fixation or an existing idea in the market for those early concepts as the initial ideas lack distinctive features and are too fundamental to bring about any significant change.

Concept Description:

The final selected concept is a Western design called Frontier Frenzy. In a parallel western-themed universe, the University of Michigan's Mechanical Engineering Department has embraced the challenge of transforming a Western Ann Arbor into the most formidable town in the West. Set in the Wild West, the ME250 robot machine cowboys (RMPs) need to manage life in their outpost town. Contracted by the local Sheriff's department, they need to clear the town of robbers, ensure the gold miners have clean air, wrangle up some horses from the prairie, and do this all while dealing with the rough terrain. By the end of the day, they need to have done all that and still hang up their hat and make their way to their homes by the evening. Students will work in teams of 4-5 members to design, construct, and test an RMP (Robotic Machine Player). Together, with 2-3 other teams from their section, students will form a squad that is in charge of cleaning up and developing Western Ann Arbor.

In this game, students will build an RMP to complete their choice of 6 tasks. They can knock down the robbers, hang their hats, build the tracks, wrangle the horses, clear the fumes, and/or park. Not every RMP will be able to do each task, so students will need to collaborate with the other teams in their squad to decide who is in charge of what tasks. Working together will allow them to score the most points possible. All of these tasks are contained on a field of 10’ X 9’. A game list with task descriptions can be seen in Table 9.

Table 9. Game Tasks with Descriptions

Game Task	Description
Knock Down the Robbers	Students must knock over the robber pieces in order to score points.
Lasso the Horses	Students must put the ring pieces around the 3 horses to score points. The circular rings are worth more than the square rings.
Build the Track	Students must move 6 pieces of “track” into the correct location on the field to build the puzzle.
Hang Your Hat	Students must place hat elements on the hooks or in the hat bucket. Feathered hats and hats scored in the bucket are worth more points.
Clear the Fumes	Students must push a button on the Mountain at least every two minutes in the game to reset a timer and keep the game going.
Park	RMPs must be in the correct location at the end of the

	match.

In addition to the tasks that need to be completed, students will have the chance to have their RMPS interact with 2 field elements: the Mountain and the Maze. The Mountain is 5’ X 5’ with two ramps and two platforms. The first ramp has an incline of 20 degrees and the second ramp has an incline of 35 degrees. The Mountain will be important for students to engage with because it will contain game pieces that are worth more points when scored. The Maze is a series of two doors that requires two RMPs to complete. One RMP will have to continuously press a button on the right side of the Maze, while the door opens and the second RMP drives through on the left. Once the second RMP is through they can drive to the end of the Maze where there will be a second button that can be pressed to open the right side door for the first RMP. If the button is let go of at any point the door will immediately start to close. The Maze is a form of direct collaboration between RMPs and is important to the game because once the RMPs traverse the Maze, they will reach the second half of the field which is Town. Town is where most of the scoring will take place during the game. It contains both the hang your hat and horse wranglin’ tasks fully and is where some RMPs will park at the end of the day. All of these game elements and tasks can be seen in Figure 12.

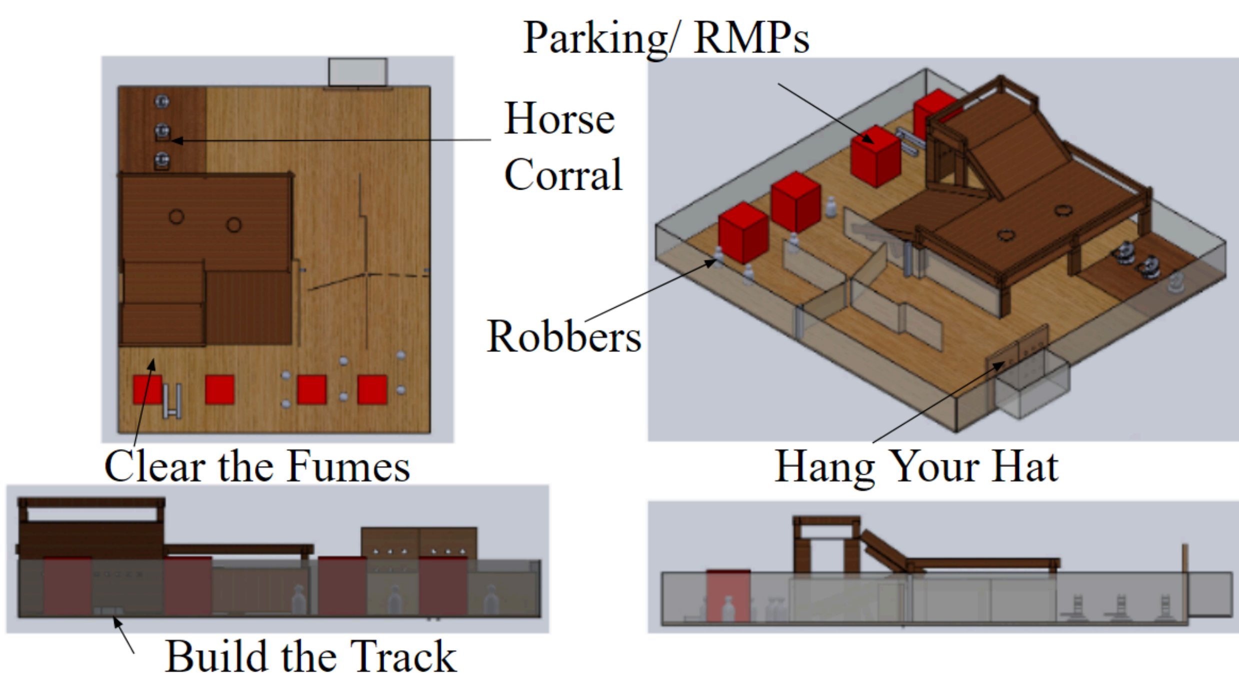


Figure 12. Figure 12 shows the full field set-up with all game tasks marked. The red cubes represent the maximum size that RMPs are allowed to get and the maximum four RMPs that will be on the field at a time. The larger dark wood structure is the Mountain and the clear plastic walls with doors is the Maze. Game elements will be scattered throughout the field. 7 square

rings will be on the floor near the horse corral, 3 circular rings will be on the middle section of the Mountain, 7 blue hats will be on the floor near the hat rack, and 3 yellow hats with feathers will be on the highest platform of the Mountain.

Engineering Analysis:

In order to assess the game as a whole, each task was broken down and individually assessed. This involved making an engineering analysis plan for each of the tasks, in order to gauge viability for the designs proposed, as well as to ensure that the specifications were being met. Fortunately, many portions of tasks were assessed through visual inspection based on CAD drawings, so the analysis mainly focused on the physical operations of the system, rather than analyzing a lot of specific design choices individually. This was possible because many of our requirements and specifications were based on size and game element interaction and using CAD allowed us to build a virtual scale model to test these requirements.]

The Maze:

The engineering analysis for the maze task centered around the mechatronic operation of the maze doors. The primary method of analysis was using first principles theoretical testing, and also creating a small empirical model to ensure that the code functioned. After deciding that the doors needed to be 10” x 24” x .125” and made out of lexan for design reasons, the first calculations done were determining whether or not the ¾” wood dowel would be able to support the doors. More detailed calculations can be found in Appendix B below, but, assuming the worst case that the entire weight of the door was supported by the end of the cantilever beam that is the dowel, it was found that the wood dowels would be able to support a 1.29 lb door, and they would only deflect by 5.405 nm; the shear force acting on the dowel was only found to be .14 MPa which is less than the shear strength of the wood dowel at 9.3 MPa. Eventually, it was determined that hardboard doors would be better suited for the maze, due to cost, rigidity, and appearance, but the weight of the doors decreased when compared to the ones made from lexan, so the previous analysis still holds.

The next design component that needed to be selected was the motor for driving the maze doors. Based on calculations that can be seen in Appendix B, it was determined that the motor required to operate opening and closing the maze doors would need to provide ~24 kgcm of torque with a gear ratio of 1:1 using the 48 dp gears we had on hand from the x50 room. This led to a selection of a 10 RPM 12V worm gear motor that has a stall torque rating of 25 kgcm. The motor selected also has an encoder, and was used to determine that the opening and closing speed of the doors will be around 1.5 seconds to cover the arc length of .9575 m. A half gear will also be used in order for the same motor to operate both doors, however an empirical test has not been conducted at this point in time to determine if this allows the doors to fully rotate open.

After acquiring the selected motor, a wiring diagram was created in order to make an empirical demo of the motor operating. This demo can be seen in Figure 13 below. Originally PID control was going to be used to operate the motor, however, after using this empirical model with the code that can be found in Appendix B below, it was determined that our goals of position control could be achieved by adding more buttons to the system, for a flag on the gears to hit in order to allow the motor to consistently stop in the correct positions, regardless of when the operating buttons are pressed by the RMPs. This also allows for easy replacement of the motor without having to retune a custom controller for the replacement part.

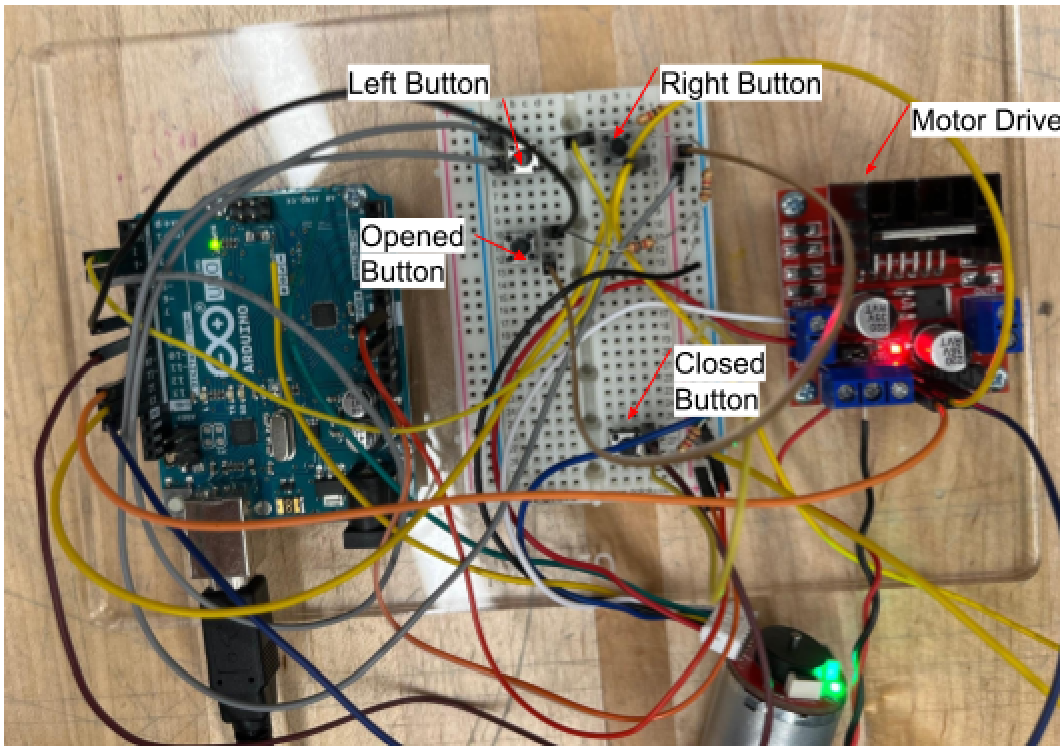


Figure 13. The demo of the Mazed motor. This demo was used as a proof of concept for using interrupts to have one motor open both directions, and only while the left or right buttons were pressed. The other buttons were used to stop the motor once the door "opened" or "closed"

The Mountain:

The mountain field element has had a lot of first principles analysis completed. In terms of the conclusions we have drawn from the calculations shown in Appendix B, we found that the weight of the RMP is unimportant in terms of being able to get up the slope, because of the motor force that can be supplied and the frictional force that counteracts gravity at the 35º angle. Since the calculations showed the 35º is possible, it was extrapolated that the "easier" 20º angle is also possible for RMPs to traverse. The mountain ramps were made out of wood instead of aluminum, since the coefficient of friction between the rubber of the tires in the 250 part kit and wood is .95 instead of the .8 between rubber and aluminum. Wood is also readily available to us for free in the x50 room which was another driving factor in the decision to use wood over aluminum like in Space Race [1]. Cost analysis is also the reason that the entire mountain field element was made from wood materials.

An empirical test was conducted with an old Space Race RMP to determine if the 35º incline was physically feasible, and not just theoretically so. The RMP was successfully able to climb the 35º incline on the hardboard ramp, so again it can be extrapolated that 20º is also feasible. The addition of grip tape to the ramp will also increase the coefficient of friction, making it easier for the RMPs to climb the mountain. After building the mountain assembly, we also stress tested the weight bearing capacity by pushing down on certain parts of it with our personal body weight, an old RMP, which can be seen in Figure 14 below, and by storing a lot of our project materials on it for extended periods of time. From this, it can be concluded that it can support the future RMPs that will be interacting with it.

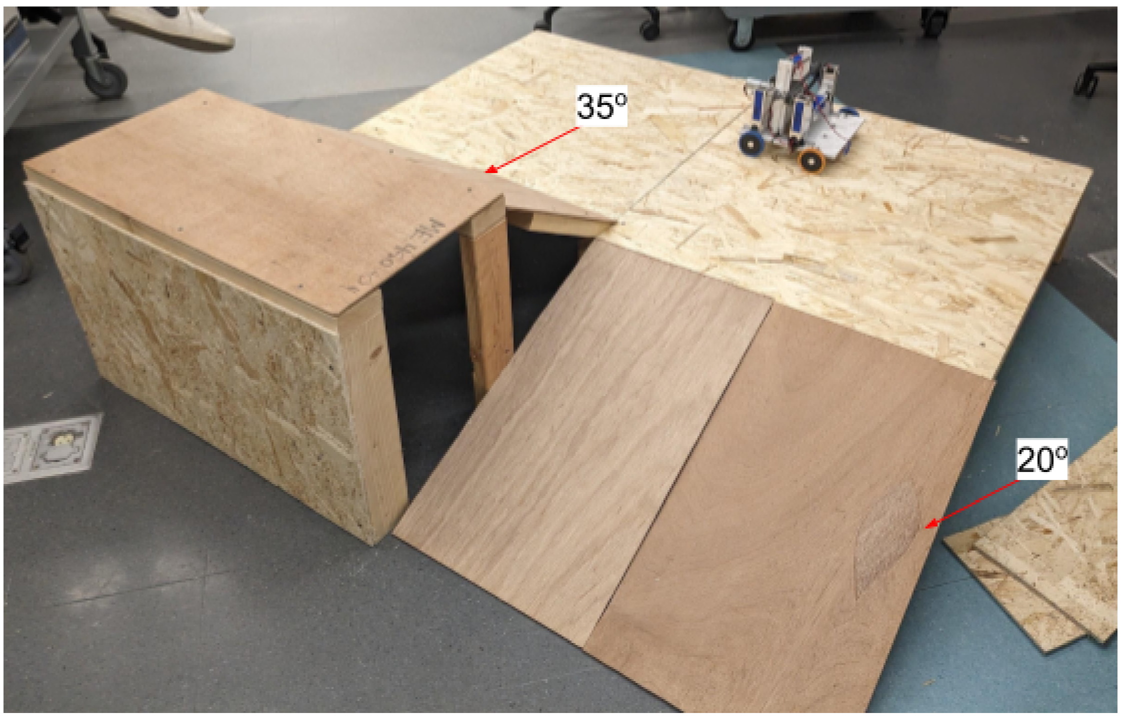


Figure 14. Isometric view of the mountain in the building process, showing the two ramps with their 20 and 35 degree angles of inclination as well as an old RMP.

Robbers:

After printing the robber pieces, it was eventually determined through an empirical test that the robbers will be attached to the board via velcro tape rather than magnets, as it it much easier to set up, and the robbers do not have to be modified by adding in a spot for metal washers to sit. This helps with the manufacturing of these pieces and these replacements, since they only need to be 3D printed and then taped. The two levels of difficulty for the robbers have also been chosen due to first principles testing, which can be seen in Appendix B below [23]. The harder variations, which will have bandanas to mark them, will not have velcro tape on the bottom, which will make them harder to knock over. It is still possible to knock them over, as was seen in an empirical test, however it is much more difficult and requires more of an impulse than the velcroed robbers.

Clear the Fumes:

For the Clear the Fumes task, we have created the complete wiring diagram and code, which can be seen in Appendix B. The code allows for the lights to be reset only when the button is pushed, and it keeps counting down the lights even when the button remains depressed; this means the RMP will not be able to just drop something on the button to keep the LEDs turned on. This code is the same code that we will use for the final task, although the wiring will be slightly different as there will be 4 LEDs per pin, since the LEDs we have are so small. After looking at electrical specifications for different LEDs, as well as price, we decided to keep these smaller LEDs, as they can be powered by an arduino and do not need an additional power source. We also decided against using 7-segment displays because, in order for the displays to be large enough in comparison to the mountain, the arduino uno would not have enough available pins or power. Looking at the simulation, it was decided that each pin will have its own 150 ohm resistor. With 4 leds per pin, if they all had a common cathode, like in Figure 19 below, the resistance would be too high and the LEDs would not get enough current to be bright. The piezo speaker wiring will not change, and all of the components for the wiring will be kept underneath the mountain to allow for easy storage and access to fix it. We will also be using 9V batteries with a barrel jack to supply enough power to the arduino, since the arduino specifications state it needs 6-12V to operate.

Additionally, an empirical model was built which can be seen in Figure 15 below. After creating this model, and confirming that the code and wiring function correctly and the chosen piezo speaker is loud enough, it was also determined that a reset button be added in order to restart the countdown between games without having to reset the arduino. This will make it easier for the GSI’s and IAs to operate the game during the design expo.

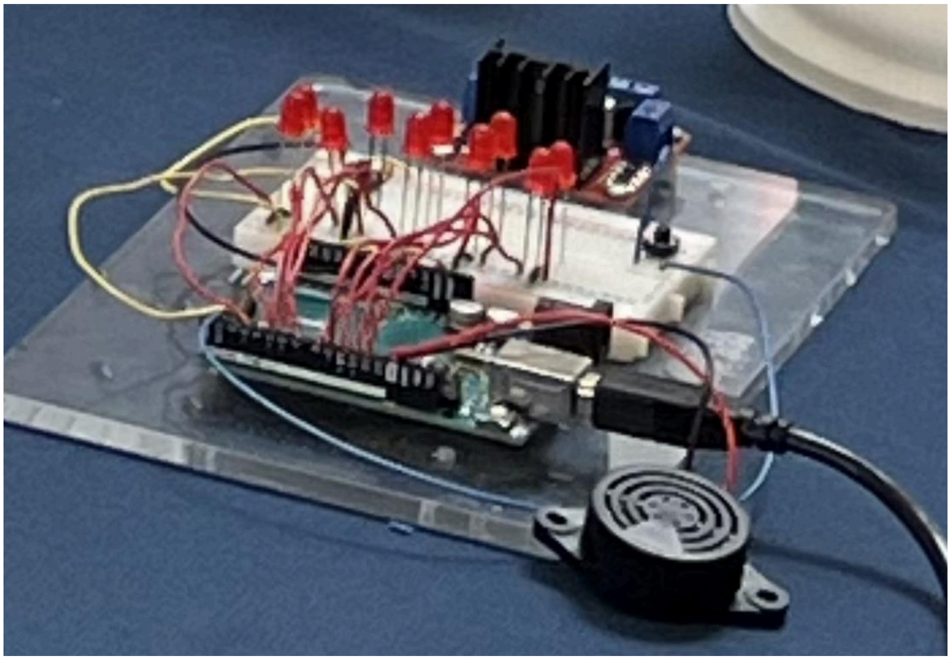


Figure 15. The empirical demo for the Clear the Fumes task. The delay was set at 1 second per light, with only 10 lights that all shared a common cathode. The only change from here to the final would be adding in the groups of 4 LEDs with their own 150 ohm resistor, and changing the delay on the LEDs to 12 seconds.

Hang your Hat:

The size of the hats was determined by looking at the cubes in Space Race, which were 1.5” all around [1]. This confirmed that our dimensions of 2.5” x 2.5” x 1.7” and flat sides, similar to the cube, allow for an RMP to handle them effectively. The material selection was also made using Space Race as the point of comparison, and, due to time and manufacturing costs, the hats will also be 3D printed like the cubes.

An empirical test was run with the actual hats and hooks to ensure that the hats stay on the hooks and do not require a high degree of accuracy. This was confirmed by us dropping the hats from a few inches above a hook, and the hat staying on the hook when dropped. Figure 22 shows the hats on the pegboard.

Horse Wranglin’:

Similar to Hang your Hat, the square and circular lassos were placed around the horse in a physical, empirical test to ensure that the dimensions of the components allowed the task to actually be completed. This can be seen in Figure 23 below.

Track Builder:

This task analysis has been completed. The materials for the track have been selected; they will be aluminum 1.5” square stock. This has been selected mainly due to the availability of them to the team from the x50 room for free, but the dimensions were desirable. An empirical model was built for the design expo, and the weight of the pieces was also deemed appropriate as they weigh less than the asteroid in Space Race, which has been successfully pushed by many RMPs before [1].

Parking:

No analysis needed to be performed on this task, as this task just requires an RMP be able to move around the board.

Final Design Description:

To complete our deliverables of designing and manufacturing a new playing field as well as writing a game manual for ME 250 Design and Manufacturing 1, there wasn't much difference between the build design and the final design. For this project, a final field was created and presented to the sponsor. This meant that the build designs that were created were mostly made for testing and prototyping purposes and did not encompass the full field. The build design mostly included the first iterations of the game elements. Most of the field, such as the base and the mountain, did not have a build design because creating them in CAD provided us with enough information to make adjustments and decisions for the manufacturing plans and final field. The Mechanical Engineering Machine shop will be finishing some of the manufacturing to make sure that it stays uniform between past games and this current iteration. The final design was fully thought out and mostly manufactured and then presented to our main sponsor Professor Mike Umbriac so that he could use it in his next ME 250 class.

For the Build Design, low-fidelity prototypes of the Robber, the Rings, and the Hats (which were all game elements) were made. These elements had build designs because they were things that the team wanted to be able to hold and interact with before they were given to an RMP to work with. The Robbers, Hats, and Rings had low-fidelity prototypes made out of PLA and printed on the University of Michigan 3D printers that were accessible to Mechanical Engineering students and free to use. Due to all of the used prototyping materials being freely available to the team, no budget was allocated to prototyping or the build design. By having low-fidelity prototypes, it was possible to use visual inspection to ensure that the game elements were suitable for the game tasks. This could include how the elements interacted with RMPs or how they met requirements and specifications. The manufacturing plan for all of these game elements was to design them in CAD (in this case SolidWorks), convert them to Gcode (whichever was appropriate for the used 3D printer as the school had multiple different types that were usable to the team. It was most likely an Ender), and then to print the element. This process was repeated for as many iterations of each game element as needed. In this case, the team expected that tolerances would not be extremely important for these prototypes, and the normal tolerance of a 3D printer would be appropriate (normally ± .1mm). The CAD for these game elements can be seen in Figure 16 below. The last build design translated to the final design. The goal of the build designs was to work out all bugs and come to the final design. Everything discussed in this section will be the final design as it is the same as the build design.

Figure 16. Figure 16 shows the final build designs for the Robber, Hat, and Circular Ring, respectively. These were the models that were printed as the last prototypes and that translated into the final designs.

For the Final Design, a full CAD mock-up of the field was created. An isometric, top, right, and left view of the field can be seen in Figure 17. This field will include 8 tasks/ field elements for RMPs to interact with.

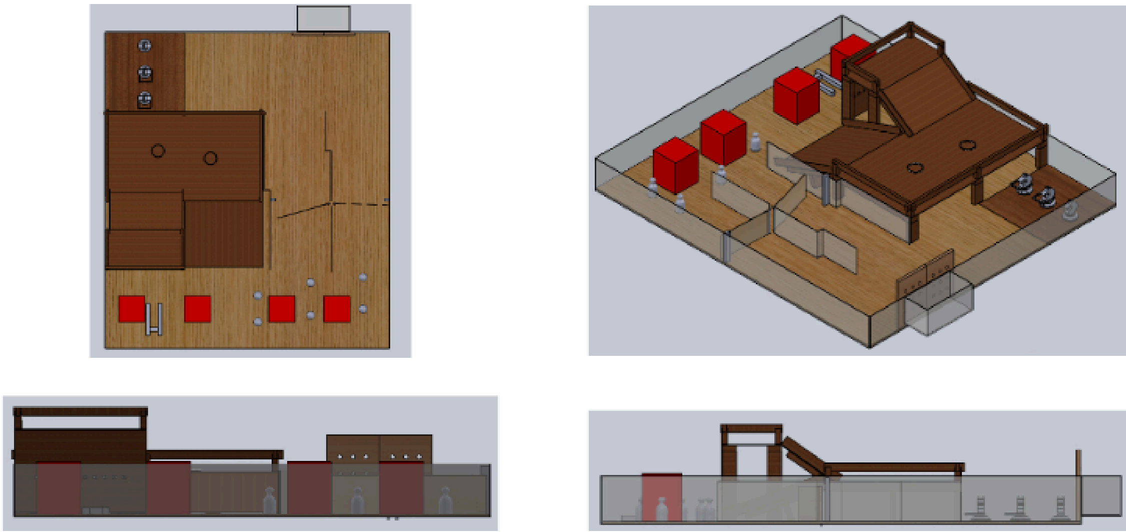


Figure 17. Figure 17 shows the final CAD of the playing field with all game elements installed. The 4 red blocks represent the maximum size of 4 RMPs that would be present during one game. The large ramp and platform is the Mountain, the plexiglass walls are the Maze, and the board with holes is the hat rack. The clear the fumes task can be seen by the holes in the side of the mountain, the hats and rings for Horse Wranglin’ and Hang your Hat can be seen scattered throughout the board, the track puzzle location can be seen in front of the mountain by Clear the Fumes, and the robbers can be seen in the bottom right. The horse plains are located in the top left corner behind the Mountain. The field is 108 inches by 120 inches, as that is the maximum size the field can be.

The first task is Building the Tracks. This task can be seen in the lower left corner of the top-down view from Figure 17. Building the Tracks is a task that will have 6 “puzzle” pieces that need to be placed in the correct position on the ground of the playing field. Students will know where to place each part based on a drawn outline of each part on the ground. Each piece will have one correct location. The 4 RMP alliances will get points for each train track part they can place in the correct location. In order to acquire and move the pieces, RMPs will need to use rotational motion, which will meet one of the key requirements for this project. The train tracks are made out of Aluminum stock that is found in the X50 room and have dimensions of 4 1.5x12x1.5” track sections and 2 1.5x3x1.5 " middle sections for students to push. The outline of the track locations on the ground will be done with tape. The manufacturing plan for these parts was to take the aluminum stock to the machine shop and use the horizontal band saw to cut them down to the correct length and then sand away any burrs using a file. The horizontal bandsaw has a tolerance of ±+. 125”, which is fine for this part and noted for students in the game manual. This task was tested by building the 6 pieces and then having an old RMP from a previous game push the bars. By allowing students to be able to weigh each piece, this task will give them a great opportunity to work with force diagramming (which is a big part of the course’s curriculum) and they will need to be able to use rotational motion to solve this task (which is a key requirement and specification). This task was successfully completed and worked as intended.

Figure 18. Figure 18 shows the final build for the Build the Track task. There are two of these sections on the board. There are four of the large sections that are 1.5x12x1.5” and two of the sort sections that are 1.5x3x1.5 ".

The second task is Clearing the Fumes. Clearing the Fumes is not a task that scores points, but it is important to the game because it allows the 4 RMP alliances to use the full 5 minutes of gameplay. At the 2-minute mark in the game, one of the RMPs will need to hit a button in order to “clear the fumes” and allow the game to keep going. If the button is not pressed then the game will end early. This event will occur again after another 2 minutes, meaning it must be completed twice within the match to get the full 5 minutes of playtime. This task allows for indirect collaboration between the teams on the alliance by making students collaborate to decide who is going to be in charge of this task, and, if this one RMP doesn’t do their task, the whole alliance will be done. The button that “clears the fumes” will be located on the middle platform of the mountain, and the lights that will blink as a timer will be located on the back of the Mountain. This task can be seen in the leftmost corner of the isometric view in Figure 17. The wiring for this task has been completed virtually and physically. The virtual layout can be seen in Figure 19. By testing virtually, the team was able to make sure the wiring would work and determine how much wire was needed before making any cuts or circuits. Once the virtual design worked, a scaled-down model was built and fully worked. This task was successful in its build. In order to manufacture this game task, the ⅛ thick board of wood was cut to size (30’’ by 35’’) and then the board was marked using a pencil and tape measure at each spot a light will be. Then using a hand drill, holes were drilled into the board and then lights were inserted. The Mechanical Engineering machine shop team will finish the wiring on the back side of the board over the summer and then reattach the board with screws into the frame of the Mountain. The LED lights are 7 mm.

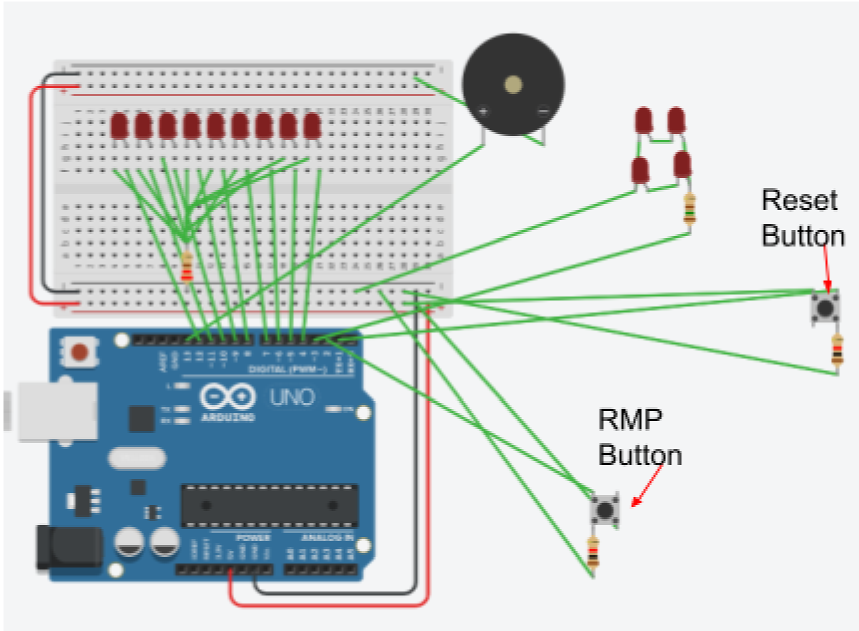
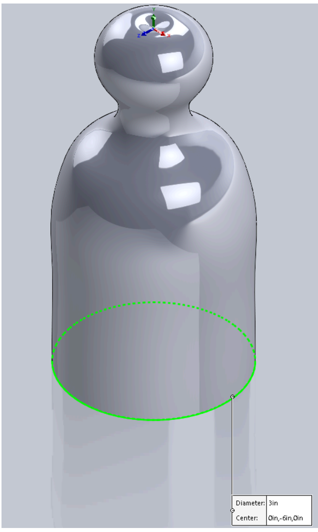


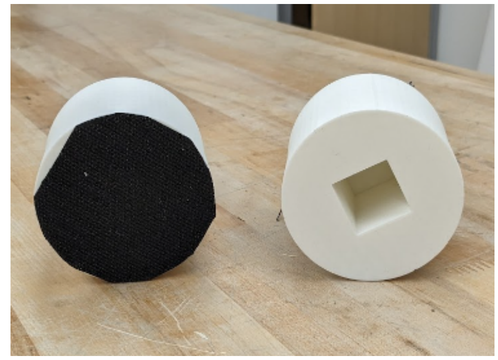
Figure 19. The wiring diagram of the Clear the Fumes task. The LEDs will all follow the group of 4 LEDs seen on the right side, each with their own 150 ohm resistor. Both buttons will also have a 1000 ohm resistor.

The third task is the Robber task. On the field, there will be 6 Robbers that RMPs will knock over to score points. They can be seen as the small dots in the bottom right-hand corner of the top view of Figure 17. There are 2 different strengths of Robbers (three of each strength). This is achieved by attaching velcro to 3 of the Robbers and not to the other 3. The velcro makes it easy for the Robbers to be knocked down because they have a better leverage point to push on. The Robbers that are not attached to the field with velcro are able to slide, making students think critically about where to hit the Robber in order to knock it down and how. The Robbers without the velcro are worth more points. All of the Robbers have a height of 6” and a base diameter of 3”. They were manufactured by CADing them, converting their files to Gcode, and then printing them out of PLA with a 35% infill for increased durability. The manufacturing plan for the final design of the Robbers was the same as for the build design. The Robbers that do not have velcro are distinguishable by the little bandanna they wear. The final Robber build can be seen in Figure 20.



(A)

(B)



(C)

Figure 20. Figure 20 shows the CAD model for the Robbers, the final print of the Robbers, and how they are differentiated with velcro, receptively. Figure 20A shows the base dimension is 3 inches.

The fourth task is the Maze. Although completing the Maze does not earn teams any points, it is an important aspect of the game because it allows teams to cross from one side of the field to the other (from the Prairie to the Town). The side that the teams start on will have tasks that are worth fewer points than the opposite side of the field. This means that in order for teams to have access to the high-scoring tasks they must use the Maze. The Maze has two paths (one left and one right) each with a door that keeps the other side of the field closed off. In order to get to the far side of the field (the Town) RMP A will press the button in the right-hand Maze to open the door of the left-hand Maze. This will allow RMP B to traverse through its Maze and hit the button at the end of its path. This will open the door on the Right side of the Maze and allow RMP A to traverse through the Maze. When the button is not pressed the doors will shut. The buttons will also be recessed and up high, in order to make sure that no team can place something on top or in front of the button to keep the door open. This recessed feature was included after talking to our stakeholders about ways that students might try to break the game and avoid the need for direct collaboration that the Maze creates. By having one RMP open the door for another RMP, direct collaboration is introduced into the game and meets the requirement of having collaboration be a part of the game. A detailed functional drawing of the Maze can be seen in Figure 18. In order to manufacture the Maze, 9 sections of plywood were cut, all at a wall height of 10 inches. These wall locations can be seen in Figure 17. From there these sections will be attached to the field using L-brackets. All of the pieces and parts have been cut and sanded, ready for the machine shop to install over the summer. The doors will be attached to the field using 8 inch dowels. These dowels will have a notch removed from top to bottom . The dowel will then go through the field through bushings to allow for them to connect to the gear/motor system that will move them. The doors will be attached to a motor with a half gear that will turn on when a button is pressed, and due to the half gear, it will only open one door at a time. This was the most challenging task to create. Finding correct ways to attach the motor to the gears and the field, as well as to attach the dowel/door system to the field.

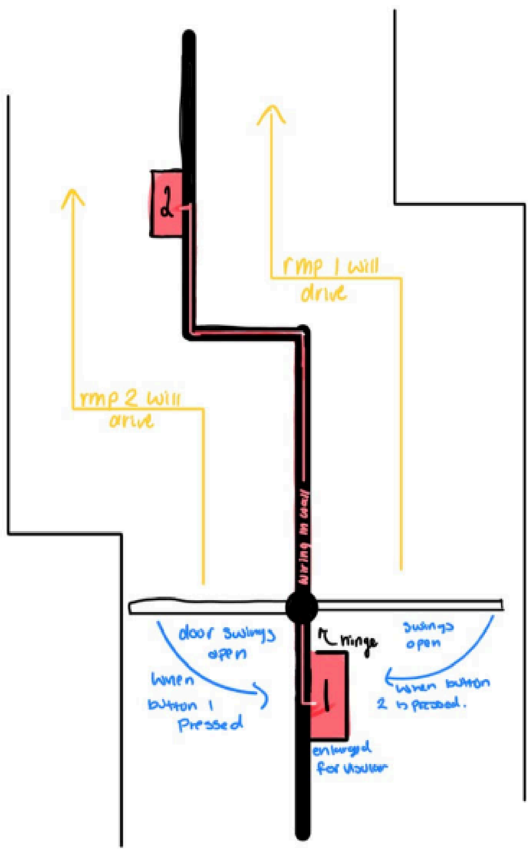
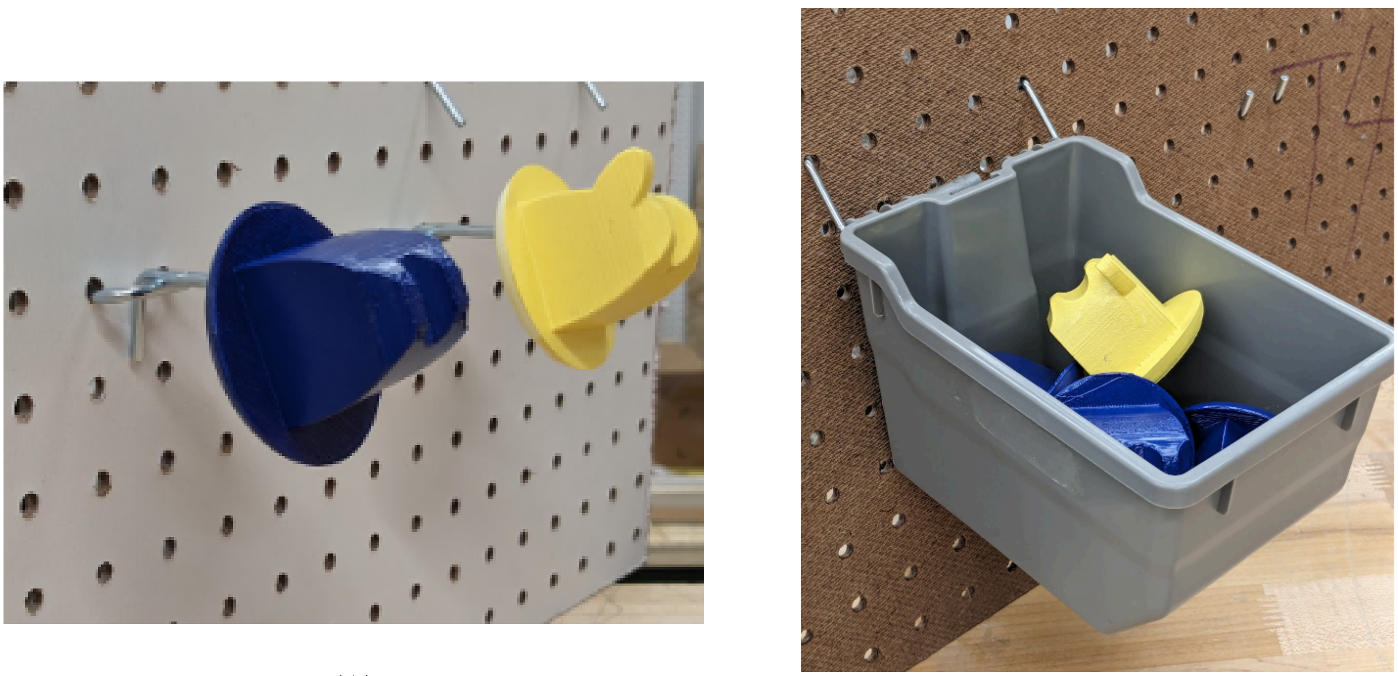


Figure 21. Figure 21 shows a drawing of the maze, and the direction of the door openings. It also shows the two button locations for the door openings, and the location of the motor. The doors are labeled by the buttons that need to be pushed for them to open.

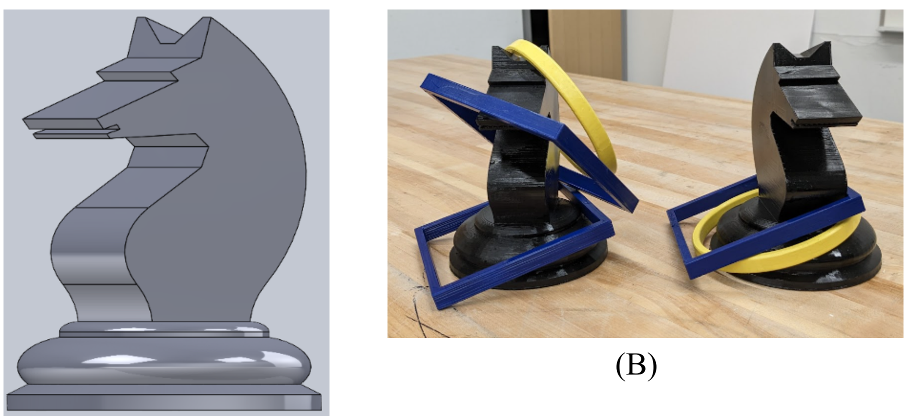
The fifth task is Hang Your Hats. In Hang Your Hats, RMPs will traverse the field and collect up to 10 small cowboy hats. These hats can be seen in Figure 22. Once the RMPs have collected the hats that they wish to score they can hang them on the hooks attached to a peg board or in the bucket behind the pegboard. These locations can be seen in the top right corner of the top-down view of Figure 17 or the rightmost concern of the isometric view in Figure 17. The hats scored in the bucket are worth more points as RMPs will need to use linear motion (one of our key requirements and specifications) to elevate the hat 12 inches over the top of the peg board and then score them in the bucket. There are 3 special hats that will be distinguished by their feather and being yellow rather than blue that will be on the highest platform of the Mountain. When scored, these yellow hats are worth double points in weather locations. Both the different types of hats and the two different scoring locations will work to meet the requirements and specifications of needing tasks of varying difficulty. The hats were manufactured by making a final CAD model, converting them to Gcode, and then 3D printing on an Ender 3. The pegboard, hooks, and bucket were all purchased from HomeDepot. The pegboard was cut to 18'' by 12' using a table saw and then sanded using a 35 grit paper. The box hangs outside of the field and is easily removable, meaning it can fit into the 10' X 9' limit. When everything else is on the field, the machine shop will screw the board into the plexiglass wall surrounding the field. These game elements were then tested by making sure humans could use them and tested with a wide variety of people at the Mechanical Engineering design expo, where the team encouraged people to come up and try the task. When testing with people, we only allowed them to move their elbow up and down, allowing for only one degree of freedom, like and RMP might have.



(A) (B)

Figure 22. Figure 22 shows both kinds of hats, the hats on the hooks, and the hats in the bucket, respectively. The yellow hats with the feather are worth double and any hat scored in the bucket is worth double. This means that the yellow feathered hats scored in the bucket are worth 4x the blue hats scored on a hook.

The sixth task is Horse Wranglin'. In Horse Wranglin', RMPs will need to collect 10 5-inch diameter rings and place them around the necks of the horses in the horse corral. Just like for the hats in Hang Your Hat, there are 3 special rings that are of a different yellow and ciculare instead of blue and square that are on the middle platform of the Mountain. If RMPs score these yellow circular rings, they are worth double points. This task will encourage linear motion to score and rotational motion to get to the rings, which helps to meet the linear and rotational motion requirements and specifications. The location of the horse corral can be seen in the top left corner of the top-down view in Figure 17. A close-up of the horses can be seen in Figure 23. The 3 horses will be 3D printed with holes in their centers. This allows for 1 inch diameter dowels to be placed into the horses and then attached with superglue. These 1 inch diameter dowels - horse systems will then be attached to the field using screws into the bottom of the field. Attaching them will be finished this summer. All of the rings (7 square and 3 circle) and the 3 horses were manufactured the same way. They were designed in CAD, converted to Gcode, and then printed on an Ender 3. After completion, they were spray painted to the colors that indicate point values, or in the case of the horses, fit within the theme. These game elements were then tested by making sure humans could use them and tested with a wide variety of people at the Mechanical Engineering design expo, where the team encouraged people to come up and try the task.



(B)

(A)

Figure 23. This figure shows the horses that the Rings will go around the horses in order to score. The diameter of the horse is smaller than the diameter of the Rings in order to make sure that they are scorable. In Figure 23B, the rings have been scored in many different ways and all count as scored. As long as the ring is supported by the horse, it will count for points. This makes it a binary yes/no score for GSIs to calculate.

The seventh task is parking. At the end of the game, RMPs will earn points for parking in their correct parking spot. There will be 4 labeled squares on the field to indicate to the teams where to park their RMP. This task will encourage students to use the whole board as the parking spots will be away from their starting locations. This movement will require the use of rotational motion to reach the correct location, which is one of the key requirements and specifications for this project. For this task, the only needed material will be tape/contact paper.

The eighth and final task is the Mountain, which is more of a field element than a task. The Mountain is a 60-inch by 60-inch by 35-inch structure that RMPs will traverse during the game. The structure has 2 ramps, the lower of which is at 20 degrees and the higher is at 35 degrees, and is made from wood to increase the coefficient of friction. The CAD model for this mountain can be seen in all views of Figure 17, where it is the large wood structure on the left side of the field. Students will be encouraged to interact with this field element due to the game elements placed on top. There will be 3 Rings and 3 Hats whose starting location will be on the Mountain, as well as the button for operating the Clear the Fumes task. If teams can work together to get these game pieces off the Mountain then when scored, these elements will be worth more points than their counterparts that started on the ground of the field. Traversing the Mountain will require rotational motion, therefore meeting that requirement will help to make some tasks harder than others, working towards the requirement of having tasks of varying difficulty. It also encourages indirect collaboration, helping to meet the requirement of having collaboration in the game. The Mountain is made entirely of wood. There is an internal structure of 2” by 4” boards that will create stability and then the whole thing is covered in ¼ inch thick wood. The full list of wood purchased can be seen in the bill of material (Figure 25). The wood was cut using the table saw and the chop saw in the Mechanical Engineering machine shop. Once all of the pieces were cut, their edges were sanded and they were screwed together using wood screws. The railing for the Mountain was made by cutting 9 1” X 2” blocks to size and then drilling a 1” deep and 1” diameter hole into them. A corresponding 1” hole was then drilled into the Mountain corner and a 2” tall 1” diameter dowel was placed in. Wood glue was used to secure the dowel and the block was placed on top. These blocks were then used to attach a thin 1.5 inch tall piece of wood all around the edge, acting as a rail to stop RMPs from falling, but still allowing pieces to slide under. This railing can be seen in Figure 24. The Mountain was fully assembled and is ready to be put on the field other than some cosmetic paint.

(A) (B)

Figure 24. Figure 24 A shows the final CAD for the Mountain and Figure 24 B shows the final build for the Mountain with a full size RMP for scale. They are the same and the final is ready for RMP use.

All of these tasks combine to the game field, as seen in Figure 17. After completing the final design for the tasks of the game and completing the CAD, it was possible to create a bill of materials. When talking with our main sponsor Professor Umbriac, it was determined that the ping pong tables he wanted us to use for the base of the game were more expensive than originally thought. This caused our budget to increase to what we need to spend. The final budget was $1700 and our final cost was $1584. The finalized bill of materials can be seen in Figure 25.

Part No.	Part Title	Supplier	Quantity	Price ($) [Total]
1	Ping-pong Table	Amazon	2	$1,200
2	Pegboard	Home Depot	1	12.24
3	Pegboard Basket	Home Depot	1	$4.48
4	Pegboard hooks	Home Depot	3	$10.44
5	1 inch diameter dowel	Home Depot	1	$5
6	3/4 inch diameter dowel	Home Depot	1	$3.67
7	48 in. x 96 in. x 0.118 (1/8) in. Clear Acrylic Sheet	Home Depot	1	$149.00
8	1/4 in. x 4 ft. x 8 ft. OSB Utility Panel	Home Depot	1	$17.78
9	1 in. x 2 in. x 8 ft. Furring Strip Board	Home Depot	2	$3.06
10	2 in. x 4 in. x 10 ft. Lumber	Home Depot	3	$12.36
11	2 in. x 1-1/2 in. x 1-3/8 in. ZMAX Galvanized Angle	Home Depot	30	$25.50
12	Battery holder	Amazon	1	$7.49
13	Arduino	Amazon	2	$54.64
14	WWZMDiB L298N Stepper Motor DC	Amazon	1	$7.99
15	Speaker	Amazon	1	$6.90
16	DC 12V high Torque Turbine Worm Gear Motor	Amazon	1	$15.15
17	Buttons	Amazon	1	$5.99
18	AA Battery holder	Amazon	1	$7.99
19	8 oz. #M230-7 Interior/Exterior Paint	Home Depot	1	$6.98
20	8 oz. #S300-4 Interior/Exterior Paint	Home Depot	1	$6.98
21	8 oz. #P270-7 Interior/Exterior Paint	Home Depot	1	$6.98
22	Sheet Sandpaper	Home Depot	2	$13.96
23	Alumnium T bar	x50 Room	As needed	Free
24	Velcro Tape		As needed	Free
25	48 DP 2" Gears	x50 Room	3	Free
26	Wood Screws	x50 Room	As needed	Free
27	1 kOhm Resistors	Mechatronics Room	As needed	Free
28	22 Guage Wire	Mechatronics Room	As needed	Free
29	150 ohm Resistors	Mechatronics Room	As needed	Free
30	PLA	Ford Maker Space	As needed	Free
31				
32				
				$1,584

Figure 25. Figure 25 shows the final bill of materials which gives us our final total spent of $1584. The BOM includes everything used in making the final project, including electronics, physical building materials, 3D printer filament, and fasteners

<u>Description of Verification and Validation Approach:</u>

Verification and validation processes are crucial to ensuring that an engineering design meets its intended specifications and requirements. To assess compliance effectively, a combination of visual and CAD inspection, theoretical analysis, empirical testing, and iterative refinement was employed in the design of our ME250 game field. Each requirement and specification was subjected to tailored verification and validation methods to ensure both conformance and efficacy of the design solution.

Requirement 1: Field Dimensions and Storage

Verification: A CAD model was used to check the playing field area. All game elements were verified in CAD to be within size limits to ensure it fits the current storage constraints. The tables utilized for manufacturing the playing field were the exact same table models that were used for the previous game, which also verifies this requirement.

Validation: Post-manufacturing, the playing field and game elements were measured physically to validate the requirements. In future once the playing field and game elements are fully assembled it will be tested in the actual storage space for final validation.

Justification and Limitation: For verification, the CAD model provides high confidence in the dimensional accuracy. The verification choice of using the exact playing field table model as the previous game is a proven choice as it is known the previous playing field already meets this requirement. CAD models assume the exact same replica of the physical model, so it might not reflect real-world variations. Assuming consistency using the same table models as prior games overlooks possible manufacturing changes or material inconsistencies. The physical validation of the playing field and game elements post-manufacturing confirms their compliance with the specified dimensions and storage constraints. Final verification in the actual storage space guarantees that the field and elements adhere to the requirements. Human error during physical measurements and assembly can introduce inaccuracies in validating the field dimensions and storage fit.

Key Results: Verification confirmed that the fully opened field area did not exceed 10 ft x 9 ft in CAD and choice of tables to manufacture the playing field. Post manufacture validation plan also confirms adherence to the requirement. Post-assembly validation plan will be the final result that needs confirmation with the requirement.

Requirement 2: Team Collaboration Requires Two Different RMPs to Interact

Verification: The game was designed with certain tasks that necessitate the collaboration of at least two RMPs. This was verified through a detailed review of the task list and descriptions to ensure at least one task was included that would require interaction between two or more RMPs to complete. This involved engineering controls (e.g. maze navigation by pressing buttons for opening the opposite side door, wall separation between both sides, and only enough space for single RMP navigation on either sides), and administrative control (e.g. clear the fume task) by setting up a scenario to complete the task.

Validation: Next semester when the game will be played, gameplay will be observed and assessed whether the collaborative elements of the task genuinely required teamwork between RMPs.

Justification and Limitation: The verification based on design review assumes the game will encourage team collaboration among the RMPs, but real-world testing during actual gameplay is needed to confirm this. Our design may not fully capture how RMPs will interact when the game is live, and there may be crafty ways teams could bypass the need for teamwork. The limitation here is that we are predicting possible strategies, which means there is a possibility that the tasks could be completed without collaboration, despite our intentions. Watching live gameplay will give us the best evidence that our design truly requires them to work together.

Key Results: So far, the design review points to at least one part of the game that requires RMPs to collaborate. Watching how the teams actually strategies in a real game next semester will be the ultimate test to see if they meet this requirement.

Requirement 3: Scores Are Easy to Calculate

Verification: To verify that scores are easy and quick to tally at the end of each round, the verification process involved a series of time trials by our team to ensure scores for each task can be calculated in less than 30 seconds by our team members by visual inspection and counting and applying basic arithmetic (e.g. visual inspection showed 3 circular rings and 2 rectangular rings on a horse, resulting in a score of 3*2 + 2*1 = 8 points for this task).

Validation: Validation for game elements was done by counting that no single game task had more than 10 game elements. Validation for timing and scoring will be done by ME250 GSIs and instructors in the next semester during gameplay. At this point, no more than 10 of each element have been created.

Justification and Limitation: The verification process for scoring assumes an environment where the scorekeepers are familiar with the scoring system. We believe that our scoring system is straightforward because our team members can calculate scores quickly. However, there is a limitation in assuming all scorekeepers will perform as efficiently as the design team. Individual experience, external distractions, and game pace can affect how easily scores are calculated in a real competitive environment. There may also be differences in interpretation of what constitutes a scorable event which was not fully addressed in the game manual, despite our best efforts to address all possible scenarios. The validation during live gameplay by GSIs and instructors will test our assumptions under actual game conditions and will offer insight into the scoring system's user-friendliness and practicality.

Key Results: Verification through time trials showed that team members can calculate scores within the 30-second goal, and task game elements were confirmed to be limited to 10 or fewer. Validation in the real game environment with GSIs and instructors will be crucial to confirming that scores can indeed be calculated easily and quickly by all scorekeepers.

Requirement 4: The Game Requires Students to Use Linear/Rotary Motion to Accomplish a Task

Verification: The game tasks were designed to involve linear or rotary motion and were verified through visual inspection of the concepts (e.g. visual inspection confirms that picking up and lifting hats to put on hat rack requires rotary motion, driving around the playing field to accomplish tasks requires linear motion). Prior years' RMP were used to test tasks for verification purposes.

Validation: Validation will occur during actual gameplay next semester, where student interaction with the game tasks will provide concrete evidence about the requirement's fulfillment.

Justification and Limitation: Verification involved assuming that prior years' RMP motion capabilities would remain consistent, potentially overlooking design changes over time. Although tasks were scrutinized for their need for specific motions, actual interaction may vary. The limitation is the assumption of uniformity in RMP designs and student engagement with the tasks. Direct observation of students attempting to complete tasks during the game will offer the most solid validation of this requirement.

Key Results: Verification using visual inspection and testing some of the tasks with previous RMPs has shown that the game tasks are designed to involve linear or rotary motion. Actual gameplay by RMPs specially designed for this game next semester will confirm if students are using linear/rotary motions as intended.

Requirement 5: Must Use Different Point Distributions for Scoring Tasks

Verification: This was verified by formally defining and calculating difficulty levels for different tasks within the game rulebook, ensuring at least two distinct difficulty levels for "Horse Wrangling", "Hang Your Hat", and "Knock The Robber" tasks (e.g. there are two different rings to wrangle the horse: circular and rectangular, of which circular rings are assessed to be more difficult to put on and thus scores more points than rectangular rings). Time required to complete the tasks were also assessed to assign varying difficulty levels (e.g. simply pushing the railtrack on the starting side is considered an easier task when compared to navigating through the maze to reach the hats and then picking up the hats to put on the rack; which reflects on associated scores for completing the two tasks separately).

Validation: In-game assessments will take place next semester to determine whether the different point distributions and assigned difficulty indeed reflect varying levels of task difficulty and engage teams in strategic play.

Justification and Limitation: The verification process for this scoring diversity was systematic, with the game rulebook defining task difficulties and corresponding scores. By assessing different task characteristics, such as the shapes of objects to manipulate or the time required for completion, we aimed to create a balanced score distribution. However, defining difficulty is subjective and may not align perfectly with actual player experiences. We have assumed that certain tasks would be universally more challenging, but the range of player skills and strategies might result in an unexpected difficulty curve. During the validation phase, actual gameplay may show that tasks thought to be difficult are easier in practice, or vice versa, thereby disrupting our intended point distribution.

Key Results: Verification against the game rulebook showed a clear differentiation in task difficulties and associated scoring. Live gameplay next semester we will be able to validate if these theoretical point distributions drive the intended diverse and strategic game play. Validation will ensure that the scoring system is reflective of the true challenge presented by the tasks and the effort required by the teams to complete them.

Requirement 6: The Complexity and Time to Manufacture Game Elements needs to be Reasonable

Verification: All game elements were designed to be manufacturable within specific time constraints using standard tools available in the machine shop. For example, a basic lathe or mill processes must be completed within an hour, and 3D-printed parts must be producible within 12 hours. This was verified by analyzing the manufacturing drawings, CAD, and processes, while also consulting with machine shop personnel.

Validation: Actual manufacturing times for prototypes were tracked (e.g. 3D printing horse pieces took 12 hours a batch), with any discrepancies leading to a review and possible redesign of the game elements to ensure manufacturability within the set constraints.

Justification and Limitation: The verification relies on theoretical and historical machine shop capabilities and student proficiencies, which might not perfectly reflect current and future variations. Unanticipated complexities in part design, student learning curves, and equipment availability could affect manufacturability. The manufacturing validation procedures may be influenced by tools' limitations and performance, as well as individual student skills.

Key Results: All individual game elements were successfully manufactured and assembled within the time and complexity constraints. The fully assembled playing field with the game elements on it required machine shop expertise and we are also now utilizing parts from the previous playing field. Thus machine shop personnel took over the responsibility to finish the assembly of parts onto the playing field.

Requirement 7: The Playing Field Needs to be Inclusive and Viewable to Students with Height Limitations

Verification: A CAD model was utilized to ensure that the height of the playing field elements did not exceed 6.5 ft, making it accessible for viewing by all students. Following manufacturing, the highest element of the playing field was measured and added to the playing field table height measurements, to confirm a total physical height of no more than 6.5ft, making it in compliance with the inclusivity standards.

Validation: Following full assembly, the game field bottom to top points will be measured again to confirm final total height to be no more than 6.5ft. When the game is set up next semester, direct observation and feedback from students will validate whether all students can comfortably view and interact with the game without height constraints impeding their experience.

Justification and Limitation: By using a CAD model and subsequent physical measurements, we have taken careful steps to create a playing field that can be enjoyed by all students, irrespective of their height. Our verification ensures that no game elements extend beyond 6.5 feet in height, which is based on standard design considerations for inclusivity. Despite these precautions, there is a limitation in that measuring physical structures does not entirely capture the viewing experience from different angles and distances during gameplay. Students with height limitations might face challenges that a static model cannot predict, such as line-of-sight issues caused by standing participants or in-game obstructions not accounted for in the height measurements. Validation will involve real-world testing, including gathering input from students of various heights to assess whether the playing field is truly inclusive and viewable.

Key Results: Verification processes, both CAD modeling and physical measurements, have demonstrated compliance with the height limitation requirements, with all elements staying below the 6.5-foot maximum. However, the confirmation that the playing field is viewable and inclusive to all students will depend on their actual experiences during gameplay next semester. Feedback from students will be essential to ensure the field accommodates height differences effectively and to inform any necessary adjustments.

Requirement 8: The Colors and Shapes of the Game Elements are Accessible for Players with Color Blindness

Verification: The game elements were designed to be distinguishable in at least two ways, such as shape and color, to accommodate players with color vision deficiencies. This was verified by conducting a visual inspection to confirm these design features.

Validation: Testing with color-blind students will take place once the game is in use next semester to validate that the elements can be successfully identified as intended.

Justification and Limitation: Verification through design inspection assumes a theoretical accessibility of game elements, not considering the full spectrum of color vision deficiencies. The visual inspection's limitation is its lack of actual user experience from varying color blindness backgrounds. Validation with color-blind students will be the true measure of the game's accessibility, potentially revealing design oversights not captured during verification.

Key Results: The design phase verification has incorporated distinguishable features for game elements in shapes and colors. The upcoming validation with the target demographic will confirm whether the game is truly accessible to players with color vision deficiencies.

Requirement 9: The Playing Field can be Set Up in 15 Minutes and Have Wheels for Transportation

Verification: Estimated setup times for the playing field were calculated based on the complexity and number of game elements. The design incorporated attached wheels on key field elements to facilitate transportation, and the weight of each game element was verified to not exceed 20 lbs using scales.

Validation: ME250 GSI's and instructors will complete timed trials of assembly and movement to simulate the real setup and transportation experience next semester. Future playing field setup for gameplay at different locations will provide further validation by confirming if the field meets the setup and transportation requirements.

Justification and Limitation: We have confirmed that each game element is light enough to move easily and the playing field included wheels for transportation to meet the setup and mobility requirement. However, our estimations do not account for variations in individual speed and ability to set up the field, nor do they consider potential obstacles or difficulties encountered during transportation. There is also a limitation in assuming that wheels on elements will always function smoothly, which could affect transport and setup time. The real test of this requirement will be when GSI's and instructors attempt to set up the field within the specified 15-minute window. Their experience and feedback during this practical test will be invaluable to assess any discrepancies between our theoretical setup times and reality.

Key Results: Our verification with weight checks and wheel incorporation suggests the playing field will meet the setup and transportation requirements. However, the validation trials by ME250 GSI's and instructors next semester will provide the necessary real-world setup times and identify any potential issues with transportation or assembly that may have been overlooked.

Requirement 10: There Needs to be Novel Tasks

Verification: Novelty in tasks was checked through a comparative analysis with tasks from the previous three ME 250 games. This comparison was carried out by the design team through reviewing past game manuals to ensure at least two tasks were offered that introduced fresh challenges and gameplay mechanics not previously encountered (e.g. Clear The Fume task stops the game prematurely if not completed in a timely manner, and no similar tasks were found in the previous three games).

Validation: Validation was done by assessing the game manual's inclusion of novel tasks not found in previous ME 250 manuals and videos (such as Clear The Fume task), ensuring it introduces fresh challenges and content to enhance the learning experience.

Justification and Limitation: Our verification relied on the thoroughness of the historical comparison carried out by the team. However, there is a possibility of subjective interpretation of what constitutes a "novel" task, which could vary among different individuals. The limitation here includes the designers' familiarity with past games potentially biasing their perception of novelty.

Key Results: Verification and validation indicate this game has inclusion of novel tasks not present in prior ME 250 games.

Requirement 11: The Game Must be Playable within a Short Period of Time

Verification: The playability within the game's time constraints was verified by estimating how many tasks can be completed within the time limit using Past RMP’s average movement speed

Validation: Time trials of the actual gameplay next semester with the newly designed RMPs will validate whether the time restrictions for each round are reasonable and within the 10-minute requirement.

Justification and Limitation: Predicting the completion time using data from past RMPs can offer insights but may not accurately reflect the pace of the new game due to possible variations in task difficulty and RMP design. The limitation lies in using historical speed data which may not align with how the new RMPs will perform. Validation with actual gameplay will provide the definitive evidence required to confirm the game's playability within the allotted time.

Key Results: Theoretical estimates suggest rounds can be completed within 10 minutes. Real gameplay next semester will either validate this prediction or indicate a need for adjustment.

Requirement 12: The Playing Field/Materials Used to Build Field Elements Need to be Durable

Verification: Specifications provided by materials manufacturers were used to confirm durability, along with engineering analysis such as force measurement tests on individual elements (e.g. putting new game elements and multiple past RMPs on the playing field and mountain at the same time).

Validation: Utilizing the same model tables as the previous game to make the new playing field already validates the durability of the playing field. Durability of game elements will be validated next semester as the game is being played.

Justification and Limitation: Manufacturer specifications and engineering force tests provide a solid foundation for verifying the durability of the playing field and its elements. The use of tested model tables from the previous game further supports our confidence in the durability of the field structure itself. However, real-world conditions, such as the frequency and intensity of RMP interactions with the field elements, may differ significantly from controlled force tests. These real-game stresses could reveal weaknesses not apparent during initial verification. Additionally, the longevity of materials under continuous use throughout the game season is not captured in short-term durability tests. Long-term wear and tear from gameplay could affect the materials differently than anticipated. Actual gameplay next semester will serve as a true test of durability, as repeated use and potential mishaps during matches will validate whether the materials used can withstand the rigors of competition over time.

Key Results: Current verification and validation methods suggest that the playing field and game elements should be durable. However, the real proof of durability will be in the observation of the field and game elements' performance under active gameplay conditions next semester. These observations will help confirm if the materials chosen meet the game's durability requirements for the entire season.

Requirement 13: There Needs to be a Compelling Storyline to Provide a Task and Purpose to Students

Verification: To verify that the game's storyline is compelling and thematically consistent, the design team read through the game tasks and assessed whether they matched the intended western theme, ensuring at least three tasks had a thematic connection (e.g., Knock The Robber clearly relates to the storyline of defending a town in a western setting).

Validation: Once the theme was set up, current and past ME250 students' perception of the storyline and its connection to the tasks were evaluated through surveys and direct feedback to validate the storyline's efficacy and engagement level. Future ME250 student’s feedback next semester will be critical for assurance.

Justification and Limitation: The verification of the storyline involved a careful review by the design team to ensure thematic consistency and compelling narrative elements were present. Validation through past and current student surveys and feedback were indispensable in gauging the storyline's effectiveness and appeal across the diverse student body. Nonetheless, determining whether a storyline is compelling is inherently subjective. The design team's perspective may not align with that of the future ME250 students, who are the end audience for the game. Participants from different backgrounds or with varying interests may not find the western theme as engaging as intended.

Key Results: Verification by the design team suggests the game successfully integrates a compelling western theme through its tasks. Initial validation confirms student engagement with the storyline. Future ME250 student's feedback will be critical in fully assessing whether students find the story enriching to their gameplay experience and whether it successfully adds depth and purpose to the game's objectives.

Discussion:

Problem Definition

If more time and resources were available, the primary focus would be on involving more stakeholders in the design process, particularly the students currently enrolled in ME250. Data could be collected by inquiring about their preferences for the current game and the types of tasks they would choose if they were designing the game, either through face-to-face interviews or email survey questionnaires. They would have been asked about what types of tasks they would like to see, where they have run into problems with the current game, and what tasks they like the best. It would have been beneficial to communicate more frequently with the Machine shop. Scheduling a meeting with them was slightly challenging this semester, and when it finally happened, we realized their significance to the build process. Engaging with them earlier would have allowed for a better understanding of which tasks are best suited for ease of manufacturing.

Design Critique

A strength in our design is that, compared to the game currently used in ME250, our game features a more balanced score distribution. We have four tasks that directly award points and two methods to enhance scoring, ensuring that each team has flexible strategic options. Based on interviews with students who have previously participated in ME250, the most significant feedback we received was that when their team's RMP responsible for picking up blocks did not function as expected, the team's total score would be very low, which greatly undermined their confidence and left them feeling discouraged. Additionally, we have implemented a more rational differentiation in task difficulty to ensure that our tasks progressively increase in difficulty, rather than only offering very easy or very challenging game tasks.

The biggest flaw in our design is our cooperative task: opening the maze doors. In designing the gate, we placed both doors in the same location and hoped to use one motor to drive both doors open. Additionally, we planned to use a half gear to ensure that while one door opens, the other remains closed. However, during our actual manufacturing process, we overlooked the speed required to open the doors. Thus, when selecting the motor, we chose one with a speed of only slightly higher than our calculated 23 RPM, at 25 RPM. This resulted in a slower-than-expected door opening speed during code testing, taking about 5 seconds to open one door. Considering that teams need to frequently traverse through the gates between both sides of the field and the entire game duration is only five minutes, the door opening time and speed are unacceptable. A promising solution is to select a motor with higher power and RPM when purchasing the motor, and to test it at higher power settings to ensure the doors can open faster. Additionally, we overlooked the angle of door opening, which means to ensure enough space for the RMP to pass through smoothly when the doors are open, we might need to set the doors at an angled initial position to ensure that, once open, the RMP can pass through without getting stuck. A possible solution is to use two motors, with each motor corresponding to the opening and closing of one door. Although this would make the door circuitry more complex, it would eliminate the need for a half gear and address the issue of insufficient door opening angle.

Risks

During the actual construction of our game terrain, the biggest issue we encountered was the assembly of the mountain sections. We initially overlooked the thickness of the wooden boards, which resulted in a misalignment when connecting the ramp to the mountain flat layers, leaving a gap. This gap poses an additional challenge for our users, future ME250 students, when designing their RMPs, as they must ensure their designs can climb the ramp and cross this gap. To minimize the difficulties caused by this gap, we used sandpaper to repeatedly sand the joints of the wooden boards to create an angle that makes the connection between the ramp and mountain layers smoother. Additionally, we plan to use low-grit sandpaper at the joint to increase tire traction without wearing out the tires. After completing the mountain construction, we realized we had not designed anything to prevent the RMPs or other smaller game elements from falling into the spaces beneath the mountain, making them inaccessible. We plan to use some leftover wood scraps to make barriers and install them on the mountain to prevent this issue.

Another risk we encountered was in designing the maze doors, where we overlooked the need for supports for the motors. We focused solely on mounting them under the ping pong table without a detailed method of installation, leading us to potentially risk installing these parts directly under the ping pong table without any frame protection. This could lead to a high risk of damage to these components during the transportation of the ping pong table. Although this will not affect our end users during the gameplay, it will create many avoidable issues during maintenance and repair.

Reflection:

Our ME 250 project emphasized inclusivity, safety, and global applicability, featuring an accessible playing field design for diverse student needs, including those with color blindness and wheelchair users. By reusing materials and opting for recyclable components, we emphasized sustainability and economic efficiency, aligning with the University of Michigan's ethical guidelines. The diverse backgrounds within our team enriched the design process, ensuring equity in our decision-making and broadening the project's appeal across various cultural contexts. Our work demonstrates a commitment to socially responsible engineering, preparing us to engage with future challenges through a lens of integrity and inclusivity.

Public Health, Safety and Welfare

Our project is highly relevant to ensuring the safety and welfare of ME 250 students. The design of an inclusive playing field that accommodates students with color blindness and height limitations demonstrates a direct focus on the welfare of all participants. A specific example here is the conscious choice of game elements with distinctive shapes and colors, directly addressing the accessibility issue for colorblind individuals. Additionally, limiting the height of field elements per ADA recommendation to ensure visibility for students in wheelchairs exemplifies this factor's relevance to our project. As participants of past ME250 games, we understand the emotional distress that may result from not being able to score points while playing the game. So we incorporated different ways to score points and also easy to score points (e.g. knocking over the robber by simply running into the game elements with relatively easy to achieve force). In manufacturing and building the playing field, we considered and addressed safety concerns while engaging with the game and playing field (e.g. sharp edges, falling on the table etc). Our design demonstrates how inclusive engineering practices can lead to safer, more accessible educational environments that cater to a diverse range of user needs.

Global Context

While our project is specific to the University of Michigan’s ME 250 course, the practices and principles we have integrated could benefit engineering education on a global scale. Transferability of the design's inclusivity features could enhance learning experiences and entice a broader, more diverse student population into STEM fields worldwide. In a global marketplace, this project stands to serve as a benchmark for engineering education that transcends cultural and physical barriers. A specific example is the incorporation of universal design principles that make the game and associated learning experiences accessible to a diverse population. Not only does this enrich the ME250 course at Michigan, but it could also inspire similar educational advancements worldwide. By showcasing how to integrate inclusivity into educational tools, we provide a template that can be adopted and modified to suit varied cultural and institutional contexts globally.

Social Impacts

Manufacture, use, and disposal of our design were considered heavily throughout the project. Social inclusion remained a priority, specifically potential positive impacts on students with disabilities, ensuring they too could fully engage with the game. Negative impacts, such as increased demand on university resources, were mitigated by repurposing materials from previous projects. Recognizing the potential to inspire or dissuade future engineers based on the accessibility and inclusiveness of educational tools, our design emphasizes social equity in academia (our design's relevance and potential societal impact was confirmed with the feedback from a past ME student with a visible physical disability. This demonstrates that our project has the power to influence future engineers by providing real-world applications of abstract concepts taught in lectures.

Economic Impacts

The design sought to minimize economic impact by repurposing existing materials and selecting items that can be recycled for future use, ultimately reducing costs. For example, by opting for recyclable materials such as steel and aluminum and reusing existing resources from past games, we created a cost-effective and environmentally responsible design, potentially reducing future expenses in material procurement and waste management. This aligns with broader university and societal goals of sustainable practices.

Tools Used

We applied stakeholder/ecosystem maps to understand the needs and influences of each group affected by our project. Life cycle costing was employed to minimize environmental impact by promoting the use of recycled materials, as illustrated by the decision to use a closet full of old materials from past games.

Cultural and Identity Influences

The team's cultural and social diversity led to a nuanced approach to design, allowing us to cover various user requirements and encouraging robust brainstorming sessions. For example, our team included members with first-generation college student backgrounds, and their perspectives were integral in making the game more relatable and ensuring it did not require prior knowledge or experience that might disadvantage any student. This inclusion offered perspectives that heightened our awareness of accessibility issues related to educational and economic backgrounds.

Differences with our sponsor's background (sponsor’s instructor identity vs our student identity) encouraged us to think deeply about the educational objectives of ME 250 and how these objectives transcend individual cultural differences to appeal to a broad range of students.

Inclusion and Equity

The power dynamics within the team and with stakeholders were balanced through open dialogues and inclusive decision-making processes. When considering power dynamics, we ensured that the sponsor's role did not overshadow the creative input from team members. This approach was reflected in our collective decision-making process, where ideas were democratically evaluated based on their merit and contribution to the project goals. Our approach to incorporating diverse viewpoints involved actively soliciting and integrating feedback from team members and stakeholders, with a commitment to valuing every opinion equally. Cultural and stylistic differences among team members and with our sponsor were bridges for creative thinking, contributing to a project that celebrates both commonalities and differences in our approaches to engineering challenges.

Ethics

Our primary ethical consideration was to ensure that the project met high standards of accessibility and sustainability. Our personal ethics, emphasizing honesty and a dedication to societal benefit, were in harmony with the professional conduct expected by the university and our future workplaces. These principles steered our design process, emphasizing user-centric innovation that would enrich the university community - our direct stakeholders including students, the instructional team, and the Mechanical Engineering department. Given that our project was not intended for the commercial market, issues typically associated with commerce did not dominate our ethical discussions. Instead, we concentrated on the responsible use of materials and the environmental implications of our design choices, reflecting the university's broader ethical standards applicable within professional settings. A notable ethical challenge we encountered involved balancing material durability with environmental stewardship. We responded by selecting materials that were not only durable but also environmentally friendly, opting for recyclable options. This decision showcases our adherence to both personal ethics and the university's professional guidelines, particularly our shared dedication to sustainability and fairness. Such conscientious choices underscore our readiness to embrace our roles as ethical professionals, blending our values with the university's esteemed ethical framework.

Recommendations:

After working on this project, the system-level recommendation we would give to anyone who might create the next ME 250 game is to try and have 2 main tasks, and then have an inventory of ~10 tasks that lab sections can choose from to get the total task count to around 8. This will increase the longevity of the game, allow for different lab sections to have completely different RMP designs since they tackled different tasks, and it adds another game strategy element.

For detail-level recommendations, they have been broken down by task.

The Maze:

Unfortunately, we were unable to construct a full model for this task, with the doors attached. Possible issues we see are: motor cannot supply enough torque and open quickly, an RMP can push through the door coming from the "Downtown" part of the field to the "Prairie" part of the field, and the doors will be unable to open the entire way with the motor only using a half gear. Our recommendations to solve these issues are: 1) changing the gear ratio to increase torque output, while sacrificing opening and closing speed, 2) having the motor be partially engaged with both doors when closed to add friction, or add a servo to block the door from opening when the button is not being pressed, 3) start the doors at a different angle than 90 degrees, so they don't need to be turned as far by the motor (this will also involve moving the wood blocker up as well).

The Mountain:

The recommendations for the mountain would be to change the OSB main platform for hardboard for aesthetic as well as splintering reasons, and also make the main platform out of 1 piece of wood instead of being cut down the middle. Our recommendation is to also have the main platform, and the two ramp sub-assemblies be attachable/detachable via friction fits with pins and/or snap fits to enable it to be easily disassembled and then reassembled. Also it would be beneficial to add in cross supports to the mountain to increase stability, however this is not required. We would also recommend adding in fabric coverings and wood boards to block openings on the side of the mountain that are large enough for game elements and/or RMPs to fit through (this is only a concern on the side of the mountain facing the Downtown area).

Wranglin Horses:

The only recommendation for this task is that there is the possibility of adding a fourth horse on the mountain that would be worth more points than the horses in the town area.

Conclusion:

In conclusion, the team successfully delivered a comprehensive and innovative game for the ME250 course, thoroughly addressing the core educational objectives set forth by the course curriculum. Through meticulous design and development, the team effectively integrated a range of tasks that not only promote understanding of linear and rotational motion but also foster crucial teamwork skills among participants. The game design, themed around a Western motif, has been validated through rigorous prototyping and testing processes, ensuring its functionality and alignment with the mechanical engineering principles taught in the course. The game has met all key constraints and stakeholder requirements, achieving an optimal balance between complexity and manufacturability. This was accomplished while maintaining budgetary constraints, underscoring the project's efficiency and resourcefulness. Additionally, the game's design considers inclusivity, ensuring accessibility for students with physical limitations and color blindness, thereby enhancing the educational experience for all students.

Even though we did not complete the construction of the entire game field as originally planned, we have completed most of the construction and testing and have handed off what was appropriate to the Mechanical Engineering machine shop. The entire mountain's construction and testing have been finished, and the codes for the countdown and maze doors have also been completed and are functional. All the game elements have also been 3D printed and just need to be placed on the field according to our CAD model. The remaining tasks primarily involve some practical construction and installation, as well as linking the ping pong tables. These tasks will be continued by the staff at the university's machine shop. We have handed over all the necessary documents and conducted a handover of the tasks through face-to-face discussions, and they are very confident in completing this project.

In our design process, we held continuous meetings with our main stakeholder, Prof. Umbriac, who expressed high praise for our design and also participated in some design improvements. Overall, the game not only revitalizes the ME250 curriculum but also significantly promotes creative problem-solving and strategic thinking.

Acknowledgements:

We express our sincerest appreciation to Prof. Michael Umbriac for his sponsorship, invaluable insights, and steady guidance throughout our project. Prof. Shanna Daly's expert instruction has greatly refined our design approach, for which we are very thankful. A special thanks to Donald Wirkner and the ME Undergraduate Machine Shop Personnel for their skillful assistance in making and assembling our design. We are also grateful for the constructive feedback from our ME250 GSIs and the encouraging inputs from the ME450 Section 02 Students, all of which have contributed to the success and improvement of our project. Their collective expertise and support have been pivotal in our learning and achievement.

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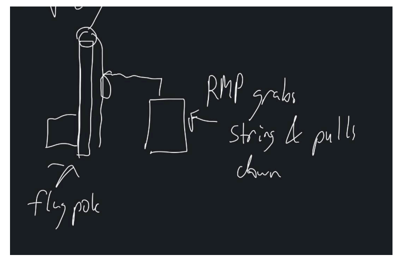
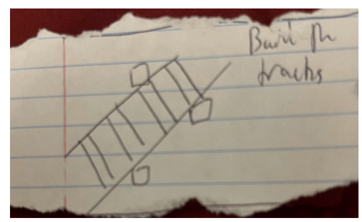
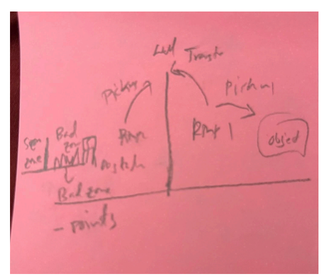
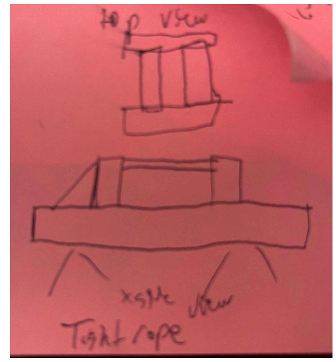
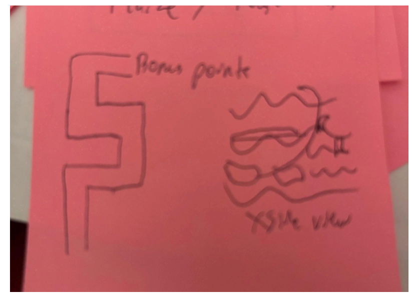
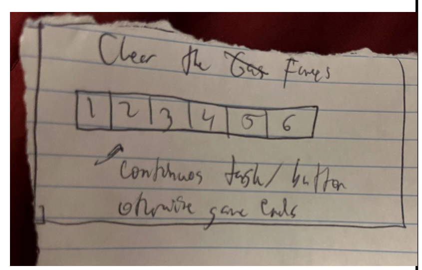
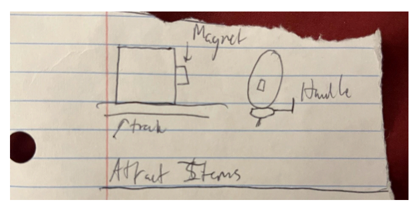
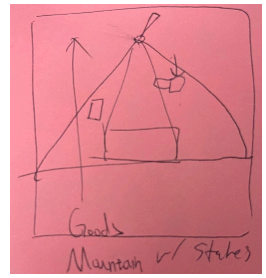
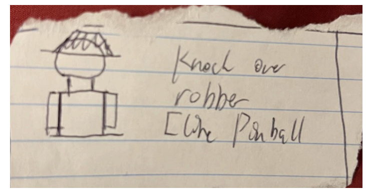
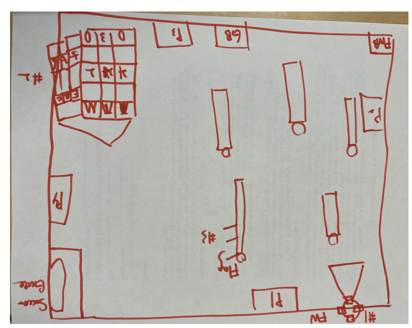
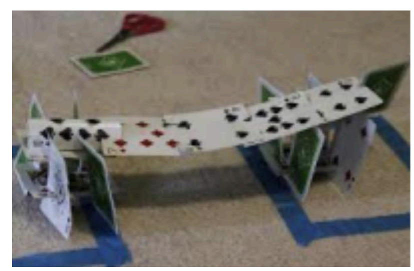
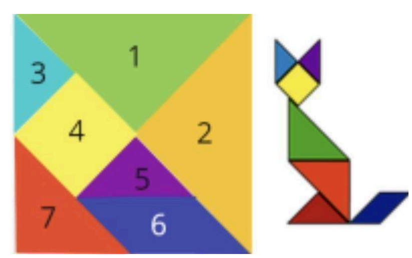
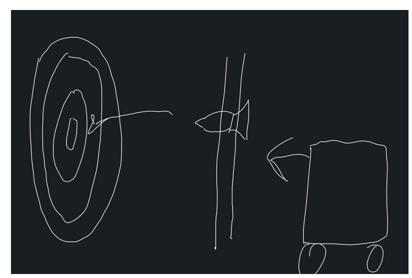
Appendix A: Generated Concepts

Number	Idea	Description	Picture
1)	Sensors to automatically count scores	This idea targets the ease of score calculation requirement by using mechatronics to automatically calculate scores in real time	N/A
2)	Raise the Flag	This idea targets the linear motion requirement, by having RMPs pull down on a pulley system to hoist a flag	
3)	Build the tracks	This task would be collaborative, as well as testing rotary motion [pushing the track pieces to the right spot] and linear by having to lift and drop on the spikes	
4)	Passing objects	This task is collaborative in nature, since RMPs will have to pass objects over a wall to each other	

5)	TightRope Walker	This is mostly a field element idea, where an RMP would have to negotiate a small space to reach a task/resources on the other side	
6)	Maze/rough waves	This is a field element idea, where an RMP would have to navigate either bumpy terrain or through a maze	
7)	Clear the fumes	This is an idea where it is indirectly collaborative, and fits the task difficulty variety by having an easier task. This is a timer that needs to be reset every so often or the game ends early	
8)	Magnet Attraction	This is a simple task for rotational motion. An rmp would just have to position the magnet in the correct direction by pushing the block to attract the other object	

9)	Mountain Climber	This is mostly a field element idea, however, with the stake planting along the way of climbing up a mountain, it tests some linear motion	
10)	Knock the Robber	This task tests rotational motion, and has task difficulty variation built in. An rmp just needs to knock over robbers, some of which offer more resistance than others [providing varying difficulty]	
11)	Choose your own adventure	This idea is to have lab sections pick 6-8 tasks from an inventory and build their own board [obviously tasks are broken by category]. This ensures more creativity since different sections might have different chosen tasks to complete	N/A
12)	Soccer Shooting	RMPs knock down the football from the towers and shoot them into the fenced gate that has to be opened by pushing a button.	

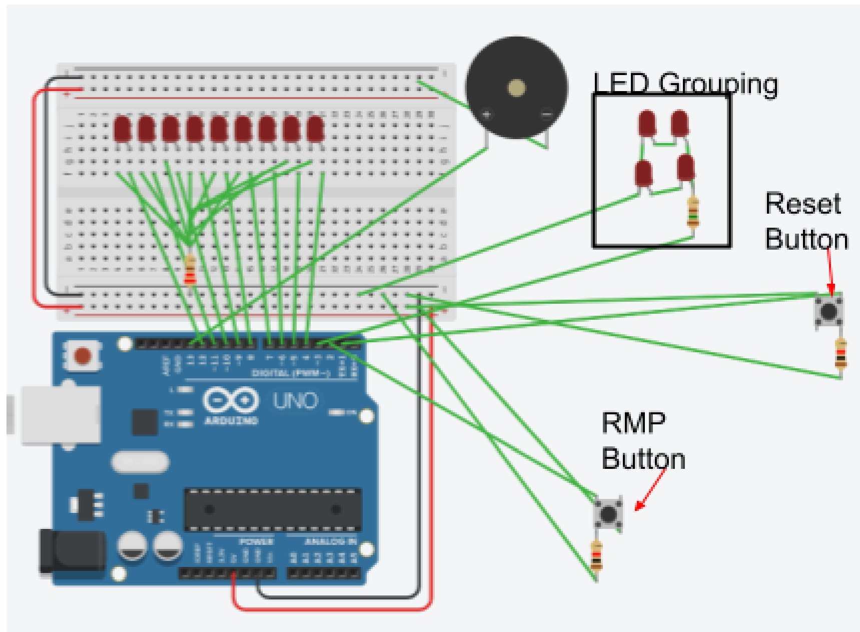
13)	Canon Shoot	RMP throws object to a distance target as obstacle do not allow RMP to drive	
14)	Risky Delivery	One RMP needs to pass an item to another robot over a tall barrier with a deep pit in the middle. If the item falls into the pit, it will be very hard for the RMP to pick it up again	
15)	Debris Collection	RMPs pick up the debris on the road to clean up the path.	
16)	Build The Bridge	RMPs build the bridge that they use to pass certain areas for extra points.	
17)	Tangram Challenge	RMPs play tangram challenges and get points if a reasonable shape is made.	

18)	Sliding Puzzle	RMPs play a sliding puzzle and get points if they finish it perfectly.	
19)	Building Block Architecture	RMPs collect building blocks from different places and build an object. The point will be given based on the height of the construction.	
20)	Throw darts	RMPs would load “darts” into some sort of container and then ram into them to launch them at a target	

Appendix B: Engineering Analysis Calculations and Code

This appendix shows the more detailed calculations for the engineering analysis, as well as containing the wiring diagrams and code for the two mechatronics tasks.

Clear the Fumes Code and Wiring Diagram:

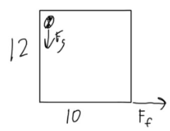



```
// C++ code
//

volatile int count=0;
volatile int i=3;


void setup()
{
  pinMode(3, OUTPUT);
attachInterrupt(digitalPinToInterrupt(2), reset, RISING);//RMP Countdown button
  pinMode(1,INPUT); //Reset Button
  pinMode(4, OUTPUT);
  pinMode(5, OUTPUT);
  pinMode(6, OUTPUT);
  pinMode(7, OUTPUT);
  pinMode(8, OUTPUT);
  pinMode(9, OUTPUT);
  pinMode(10, OUTPUT);
  pinMode(11, OUTPUT);
  pinMode(12, OUTPUT);
  pinMode(13, OUTPUT);
  reset();
}

void loop()
{
  for(; i<13; i++)
  {
```

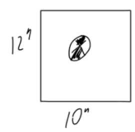
```
    delay(12000);
            digitalWrite(i,LOW);
    count++;
  }
  if(count==10)
  {
  digitalWrite(13,HIGH);
  delay(2000);
  digitalWrite(13,LOW);
    count++;}
  if(count==11 && digitalRead(1)==HIGH)
  {
    count=0;
   reset();
  }

}

void reset()
{
  if(count<10)
  {
 for(int j=3; j<13; j++)
  {
            digitalWrite(j,HIGH);
  }
  count=0;
  i=3;
}
}
```

Mountain Angle FBD Analysis:

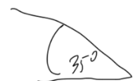
Two Cases up



2)



Case 2 see above for eqns



$F_{f30} = .95 \cdot 9.8 \cdot$ cos30 = $.98m \sin 30 = f_{gx}$

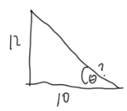
$F_{f35} = .95 \cdot 9.8 \cdot$ cos35 = $.98m \sin 35 = F_{gx}$

Tipping angle calculation

$\theta = \arctan\left(\frac{H}{B}\right) \cdot \frac{180}{\pi}$ $H = .3048m$

$\theta = 50.19°$ $B = .254m$

$35 < 50.19$



$.95 \cdot 9.8 \cdot m \cos 30 > 9.8 \cdot m \sin 30$

$8.06 > 4.9$ ✓ any mass

$F_{f30} > F_{gx}$

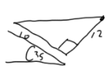
$.95 \cdot 9.8 \cos 35 \overset{?}{>} 9.8 \sin 30$

$7.63 > 5.62$ ✓

$F_{f35} > F_{gx}$ any mass

down?

will tip on way down



motors can provide 9.72 Nm of torque @ 12V

Wheels have diam $2\frac{7}{8}$in = .073025m

so $F_{wheel} = 133.12$ N

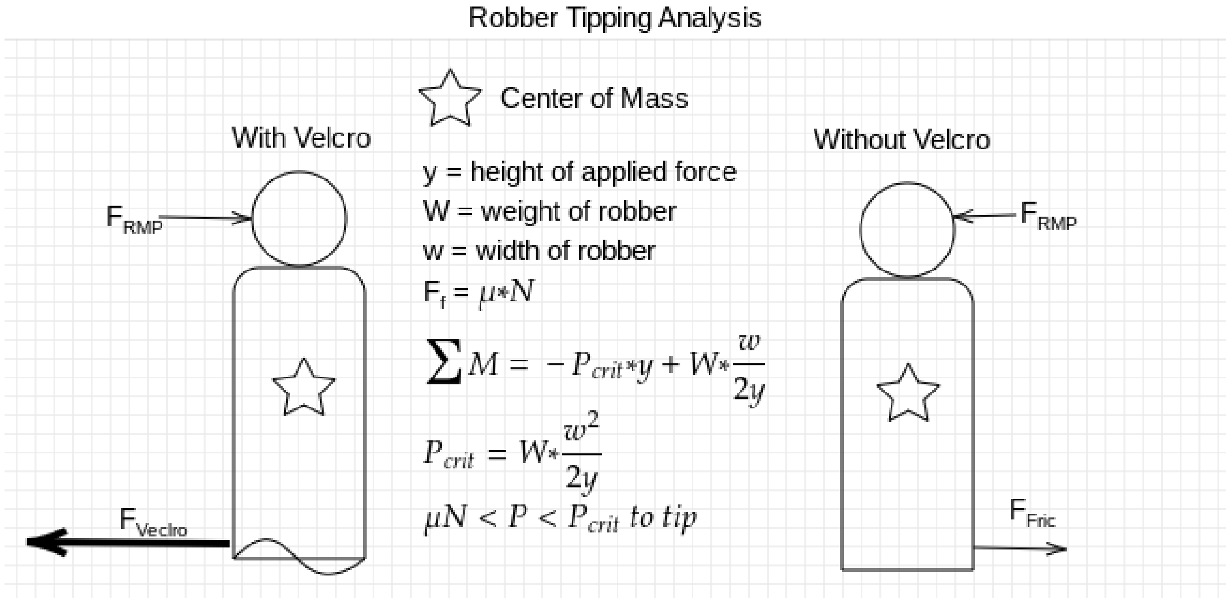
$F_{wheel\,max} + F_{f30/35} > F_{gx}$ ✓

any angle will tip in this scenario

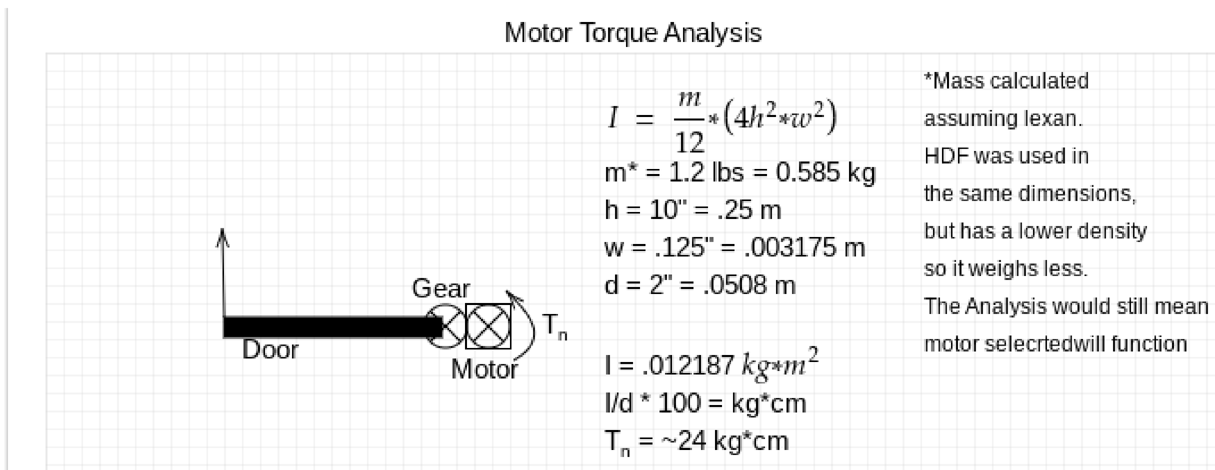
Can power up the hill

[topple?]

Robber Tipping FBD:



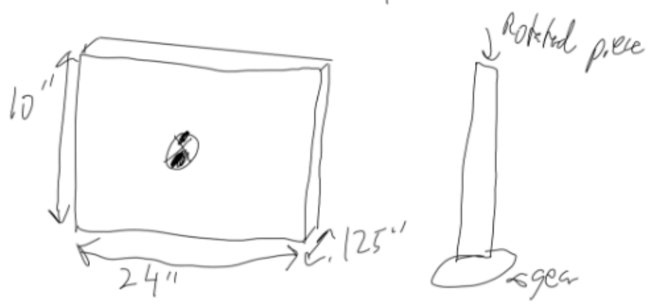
Maze Motor Calculations:

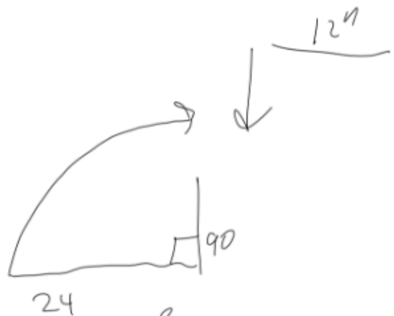


Maze Shaft Calculations:

$\rho = .043\ lb/in^3$

$V = 24 \cdot 10 \cdot .125 = 30\ in^3 \;|\; .043 = 1.29\ lbs$





$1.29\ lbs \;|\; \frac{1\ kg}{2.2\ lbs} \;|\; 30.48\ cm \;|\; 9.8$

$= 17.51\ Nm$ on dowel

$r = .6096$

$\theta = \pi/2$

$s = .9575\ m \cdot rad$

5 seconds

$.1915\ \frac{m \cdot rad}{s}$

$\omega = .314\ \frac{rad}{s}$

10 rpm gear

$\frac{10\pi}{30} = 1.04\ rad/s$

$= 1.51\ s$ to rotate

Vertical cantilever beam.

Highest moment/shear @ support

$\frac{17.51\ Nm}{.25\ m} = 70.04\ N$

[assume worst case & all @ Free end]

Shear = 9.3 MPa

$P_s = \frac{Force}{Area}$

$\frac{70.04\ N}{\pi \frac{.025^2}{4}} = 142.684\ KPa$

$.142684\ MPa < 9.3$

Won't shear

Max deflection in worse case

$\delta_{max} = \frac{70.04 \cdot .25^3}{3.205\ GPA \cdot \frac{1}{3} \cdot .0158 \cdot .25^2}$

$= 5.405 \times 10^{-9}\ m$

5.405 nm

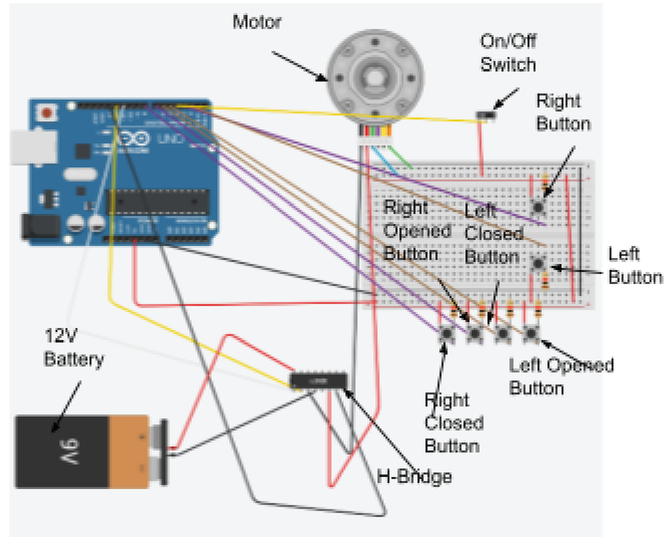
$\frac{N m^3}{\frac{N}{m} \cdot m^2}$

conservative

$\rho_{dowel} = 8\ lb/ft^3 = 128.148\ kg/m^3$

$m_{dowel} = 1.23 \times 10^{-4}\ m^3 \cdot 128.148 = .0158\ kg$

Maze Code and Motor Wiring Diagram:




```
const int LEFT_BUTTON=2;
const int RIGHT_BUTTON=3;
const int ON_OFF=4;
const int LEFT_OPEN_BUTT=5;
const int LEFT_CLOSED_BUTT=6;
const int RIGHT_OPEN_BUTT=7;
const int RIGHT_CLOSED_BUTT=8;
const int PIN_NR_PWM_OUTPUT      = 11; // Connected to H Bridge (controls motor speed)
const int PIN_NR_PWM_DIRECTION_1  = 12; // Connected to H Bridge (controls motor direction)
const int PIN_NR_PWM_DIRECTION_2  = 13;  // Connected to H Bridge (controls motor direction)


void setup() {
  pinMode(ON_OFF,    INPUT);
  pinMode(LEFT_OPEN_BUTT,    INPUT);
  pinMode(LEFT_CLOSED_BUTT,        INPUT);
  pinMode(RIGHT_OPEN_BUTT,    INPUT);
  pinMode(RIGHT_CLOSED_BUTT,        INPUT);
  pinMode(RIGHT_BUTTON,        INPUT);
  pinMode(LEFT_BUTTON,        INPUT);
  pinMode(PIN_NR_PWM_OUTPUT,      OUTPUT);
  pinMode(PIN_NR_PWM_DIRECTION_1,  OUTPUT);
  pinMode(PIN_NR_PWM_DIRECTION_2,  OUTPUT);

  // Turn on the pullup resistors on the encoder channels
  //digitalWrite(PIN_NR_ENCODER_A, HIGH);
  //digitalWrite(PIN_NR_ENCODER_B, HIGH);


  // Activate interrupt for encoder pins.
```

```
  // If either of the two pins changes, the function 'updateMotorPosition' is called:
  attachInterrupt(0, OPENLEFT, CHANGE);  // Interrupt 0 is always attached to digital pin 2
  attachInterrupt(1, OPENRIGHT, CHANGE);  // Interrupt 1 is always attached to digital pin 3


}


void loop() {
  // put your main code here, to run repeatedly:
}


void OPENLEFT()
{
  digitalWrite(PIN_NR_PWM_OUTPUT, HIGH);
  while(digitalRead(LEFT_BUTTON)==HIGH && digitalRead(LEFT_OPEN_BUTT)==LOW)
// button pressed, open door
   {
    digitalWrite(PIN_NR_PWM_DIRECTION_1,LOW);  // might need to reverse these
    digitalWrite(PIN_NR_PWM_DIRECTION_2,HIGH);
   }
  while(digitalRead(LEFT_BUTTON)==HIGH && digitalRead(LEFT_OPEN_BUTT)==HIGH)
// door has opened stop rotation
   {
digitalWrite(PIN_NR_PWM_DIRECTION_1,LOW);
    digitalWrite(PIN_NR_PWM_DIRECTION_2,LOW);
   }
    while(digitalRead(LEFT_BUTTON)==LOW  &&
digitalRead(LEFT_CLOSED_BUTT)==LOW) // Button unpressed, close door
     {
      digitalWrite(PIN_NR_PWM_DIRECTION_1,HIGH);  // rotate forward
    digitalWrite(PIN_NR_PWM_DIRECTION_2,LOW);
     }
```

```
    digitalWrite(PIN_NR_PWM_DIRECTION_1,LOW);  // rotate forward
    digitalWrite(PIN_NR_PWM_DIRECTION_2,LOW);
  }


void OPENRIGHT()
{
  analogWrite(PIN_NR_PWM_OUTPUT, 255);
  while(digitalRead(RIGHT_BUTTON)==HIGH &&
digitalRead(RIGHT_OPEN_BUTT)==LOW)
  {
    digitalWrite(PIN_NR_PWM_DIRECTION_1,HIGH);  // rotate forward
    digitalWrite(PIN_NR_PWM_DIRECTION_2,LOW); // rotate forward
  }
  while(digitalRead(RIGHT_BUTTON)==HIGH &&
digitalRead(RIGHT_OPEN_BUTT)==HIGH)
  {
digitalWrite(PIN_NR_PWM_DIRECTION_1,LOW);  // rotate forward
    digitalWrite(PIN_NR_PWM_DIRECTION_2,LOW);
  }
    while(digitalRead(RIGHT_BUTTON)==LOW  &&
digitalRead(RIGHT_CLOSED_BUTT)==LOW)
    {
      digitalWrite(PIN_NR_PWM_DIRECTION_1,LOW);  // rotate forward
    digitalWrite(PIN_NR_PWM_DIRECTION_2,HIGH);
    }
    digitalWrite(PIN_NR_PWM_DIRECTION_1,LOW);  // rotate forward
    digitalWrite(PIN_NR_PWM_DIRECTION_2,LOW);
  }
```

Manufacturing Plans:

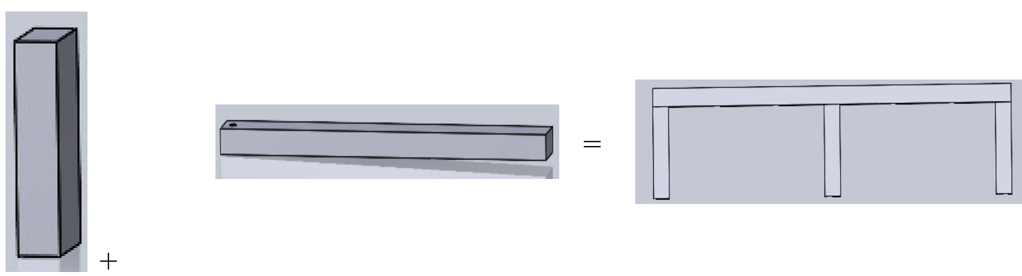
[Engineering Drawings]

Robbers:

1) Cut denim into a square
2) Tie around non-veclro robber as shown

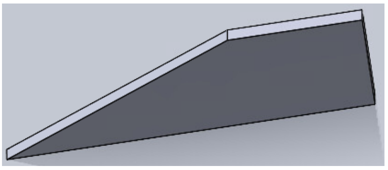
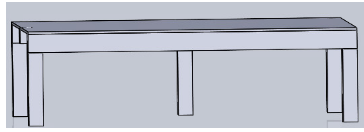
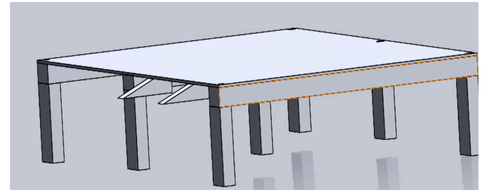
Mountain Assembly:

1) Screw together middle support pieces to create the middle platform supports as shown. There will be 3 of these

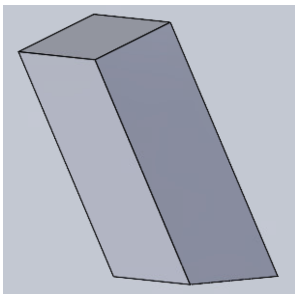
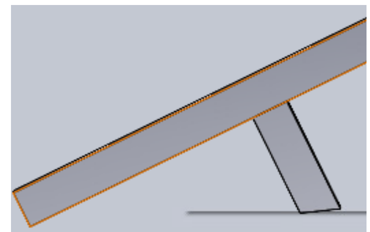


2) Screw the main platform to the supports created in previous step as shown

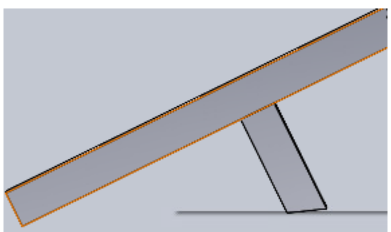
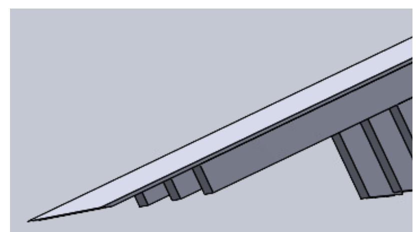
3) Attach Lower Ramp Connector to main platform as shown using screws

 +  = 

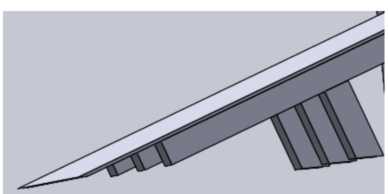
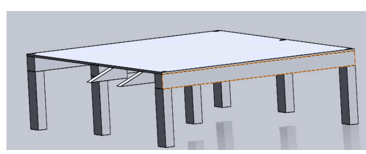
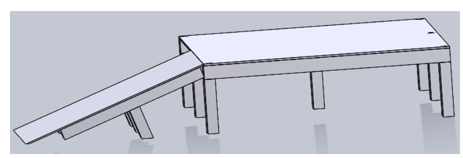
4) Attach lower ramp ground supports to the lower ramp support using screws. There will be 3 of these

 +  = 

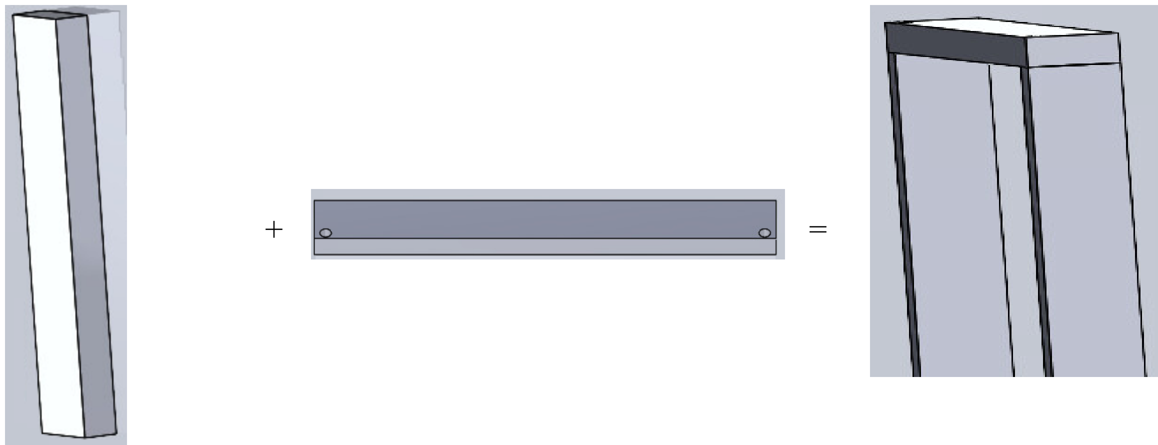
5) Attach the lower ramp to the lower ramp supports using screws

 +  = 

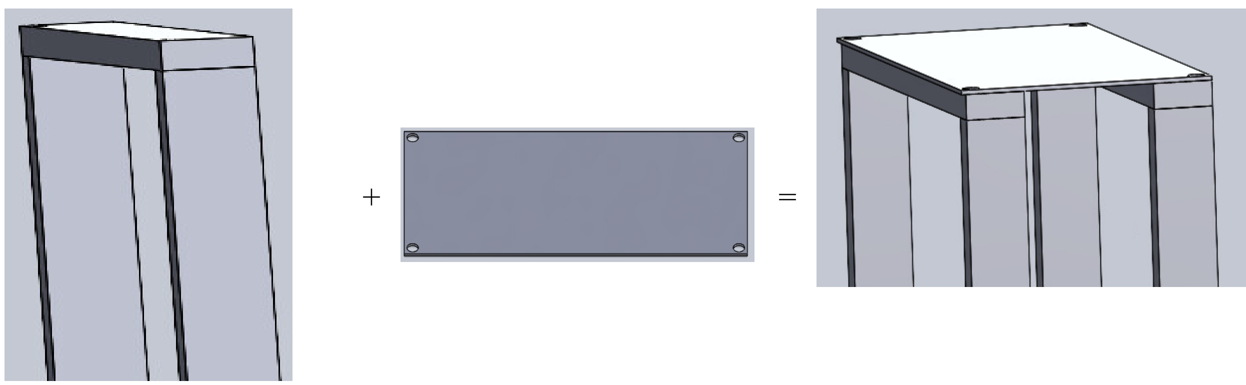
6) Attach Lower ramp to larger assembly using screws

 +  = 

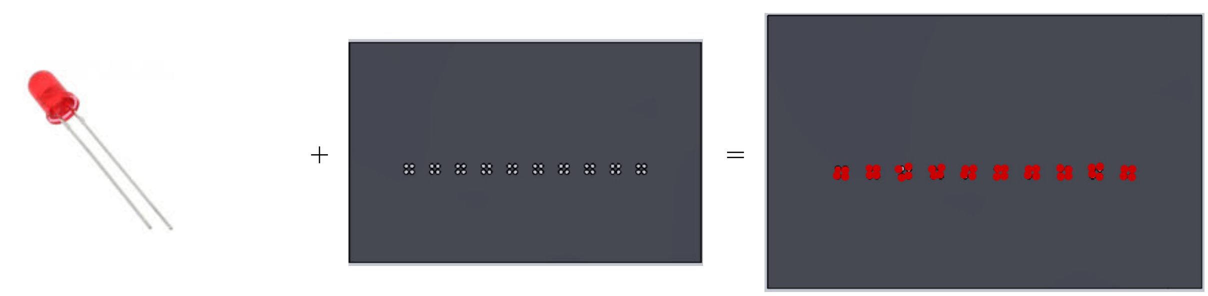
7) Create Upper Platform supports by screwing together the pieces shown below. There will be 2 of these



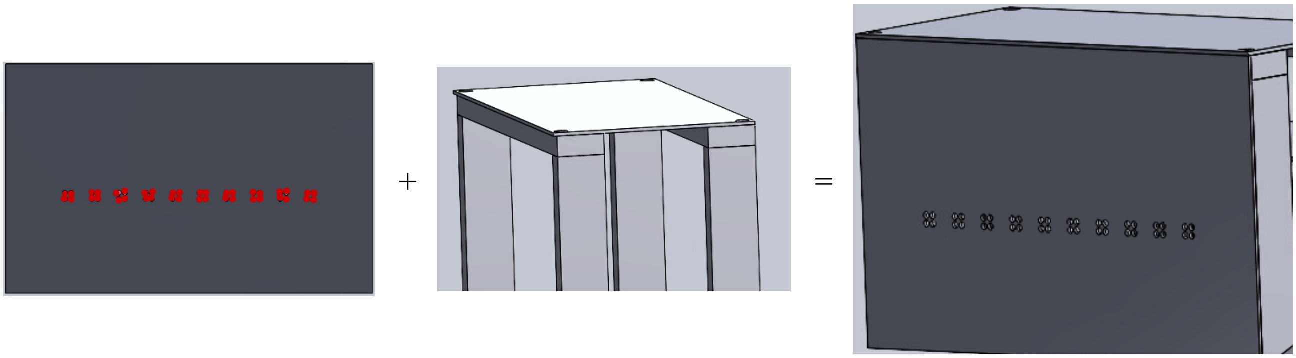
8) Attach Upper platform to supports using screws



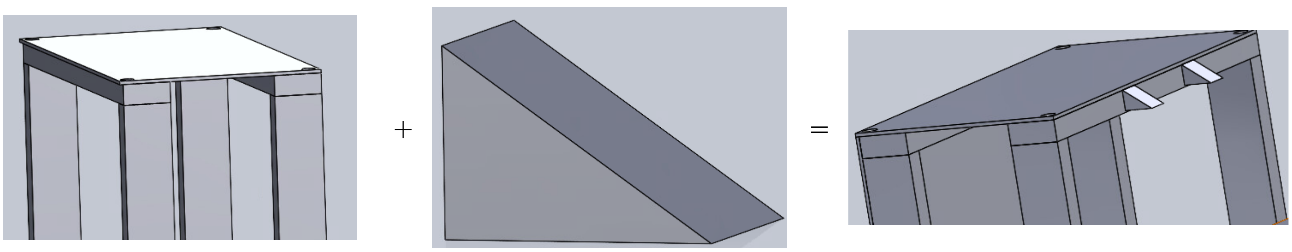
9) Glue LEDs onto front panel



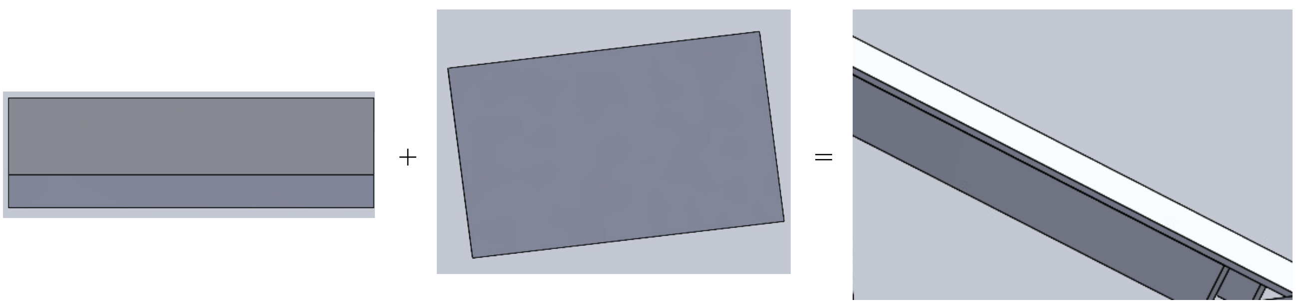
10) Screw front panel onto upper platform subassembly



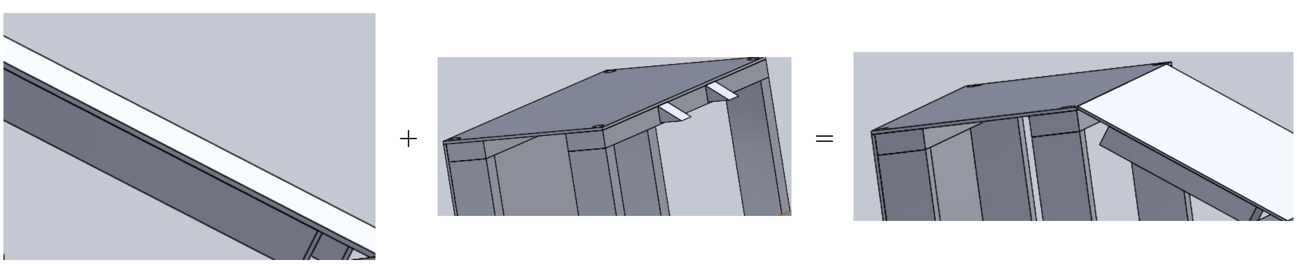
11) Attach Upper Ramp connector to Upper Platform using screws



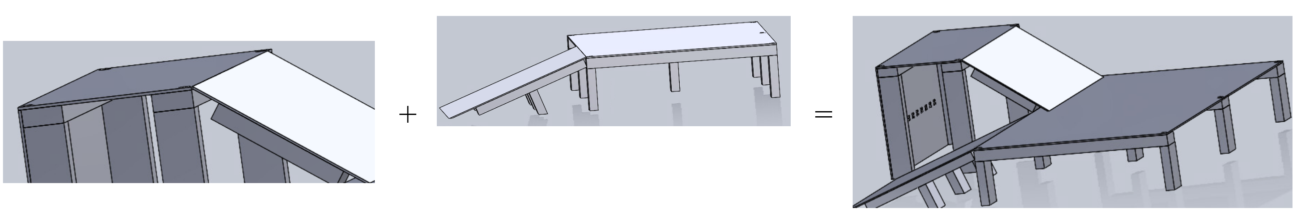
12) Attach Upper Ramp to Upper Ramp Supports using screws



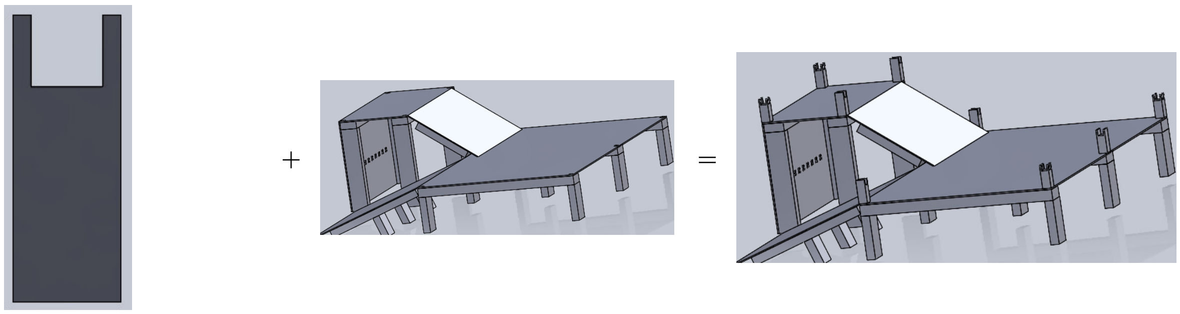
13) Attach Upper Ramp to upper platform subassembly using screws



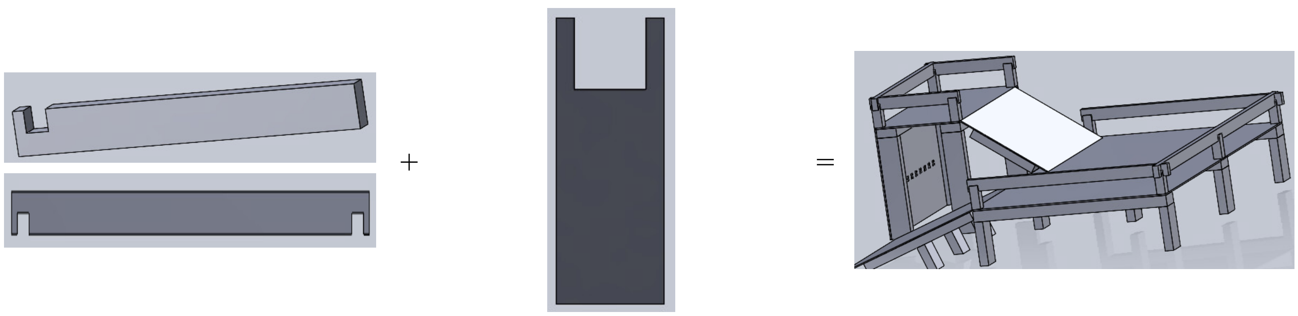
14) Attach Upper subassembly to the rest of the Mountain using screws



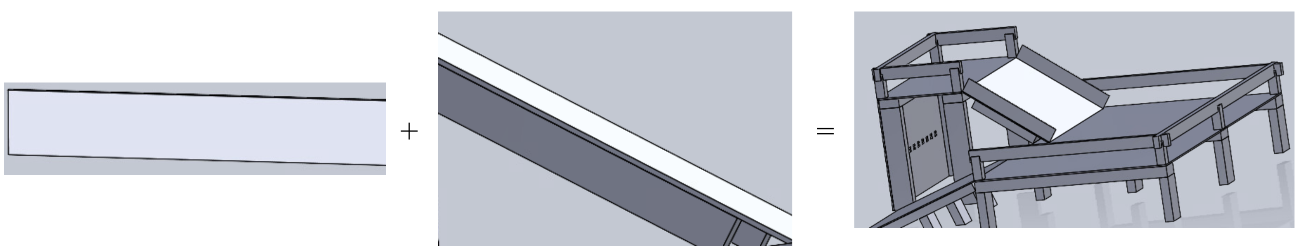
15) Attach Posts to platforms using wood pegs and wood glue



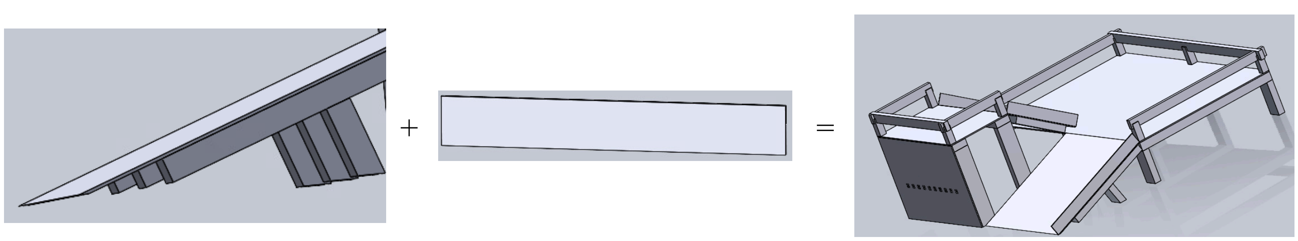
16) Slot in side railings to posts



17) Use L-brackets and smaller screws to attach upper ramp railings to upper ramp



18) Use L-brackets and smaller screws to attach lower ramp railings to lower ramp

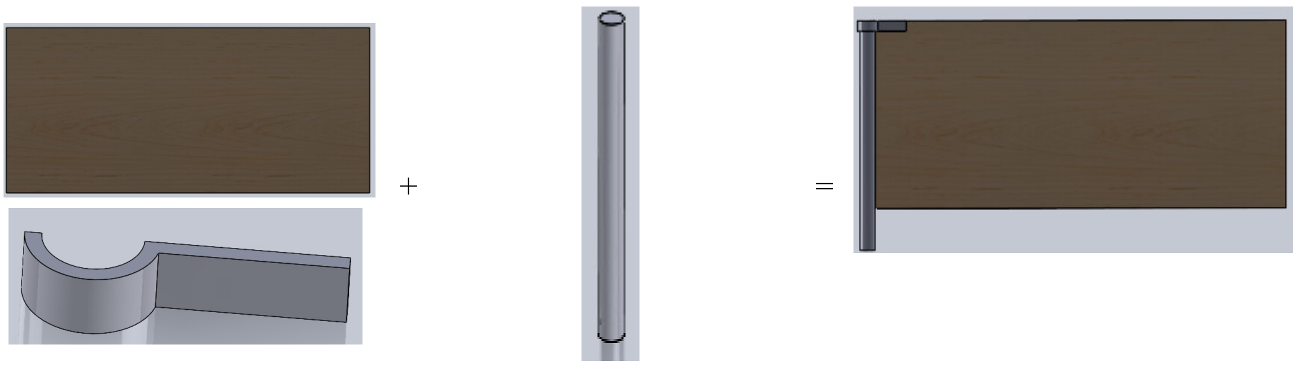


19) Glue on grip tape to the ramps

20) Paint the mountain

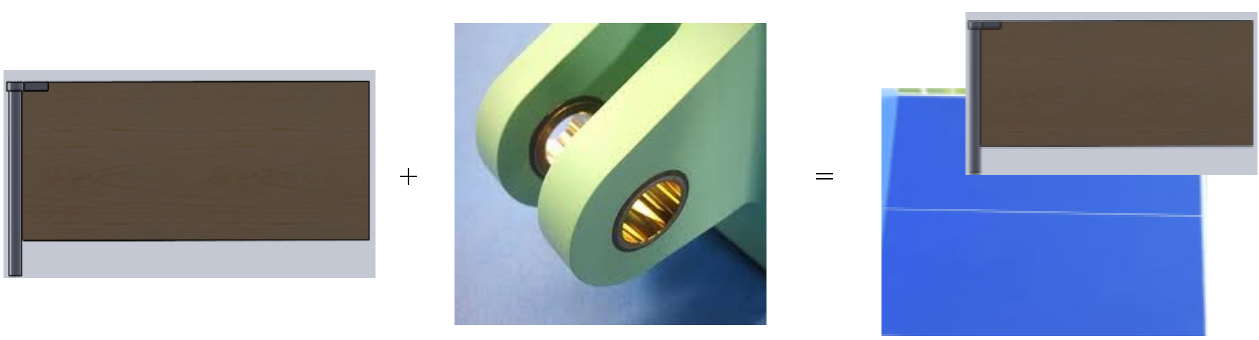
Maze Assembly:

1) Use brackets and screws to attach doors to the dowels. There will be two of these

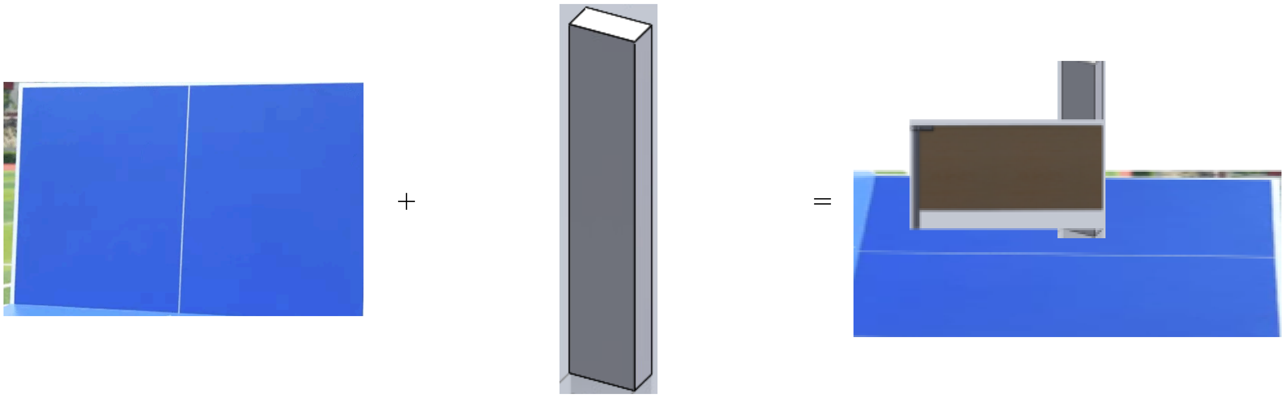


2) Drill holes in Ping Pong table and press fit bushings

3) Place dowel/door assembly through bushings



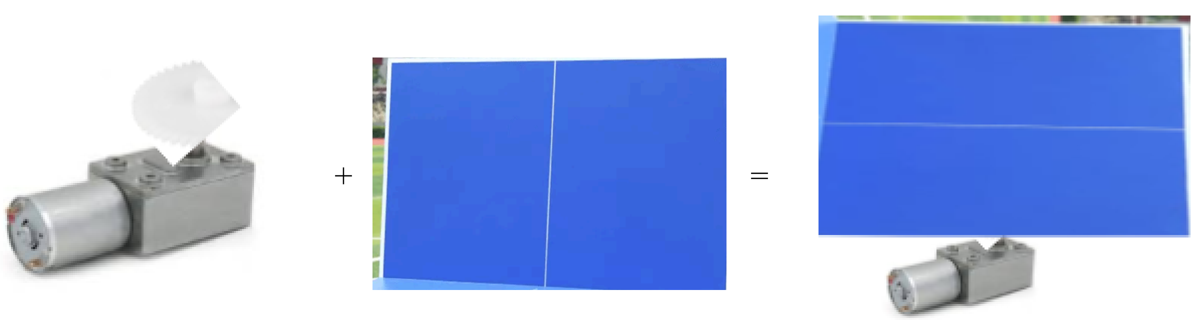
4) Screw in Hardstops to table



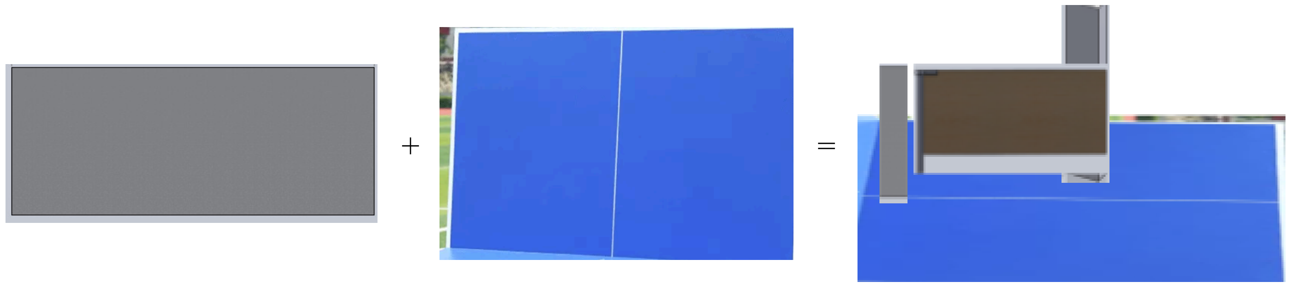
5) Use glue to attach dowels to gears

6) Use grub-screw and loctite to attach half gear to motor

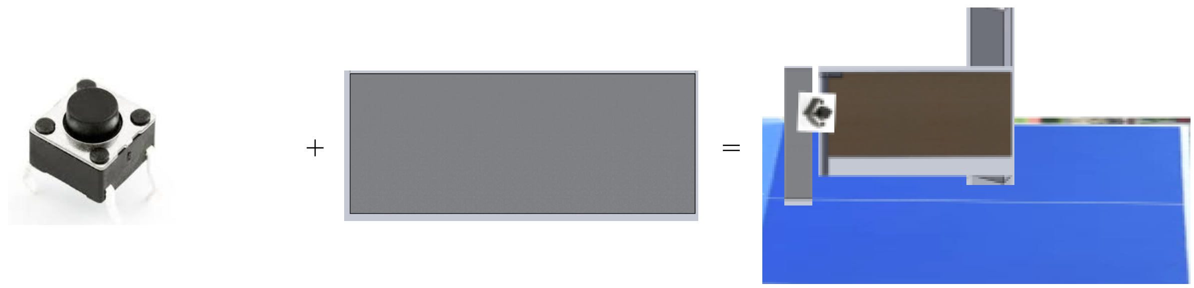
7) Screw in motor to bottom of board



8) Use L-brackets to screw wall to Ping Pong table



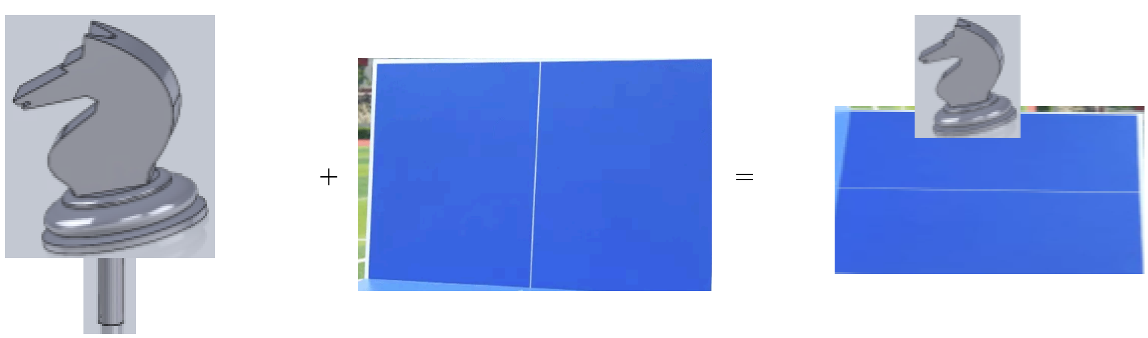
9) Glue Buttons and Button Caps to the wall



Horse Assembly:

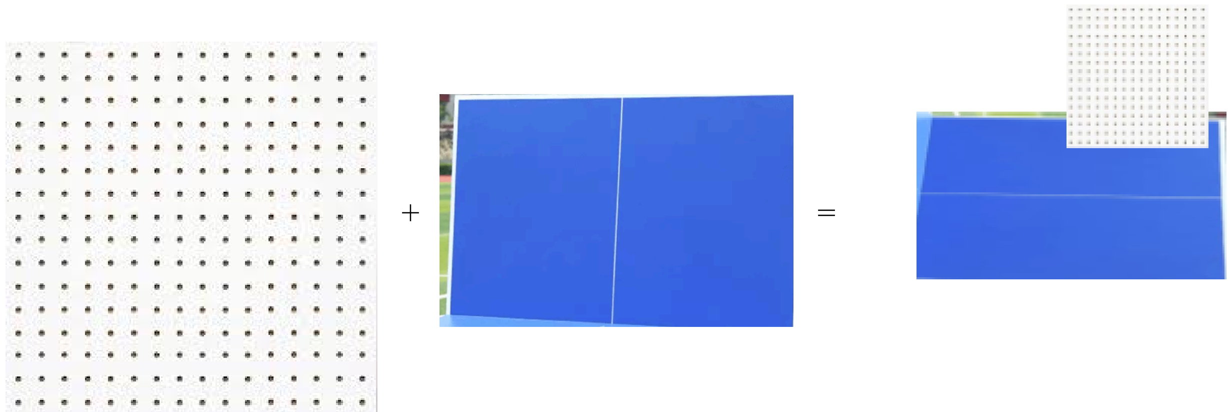
1) Glue 1” dowel into horse

2) Screw through Ping Pong Table into dowel



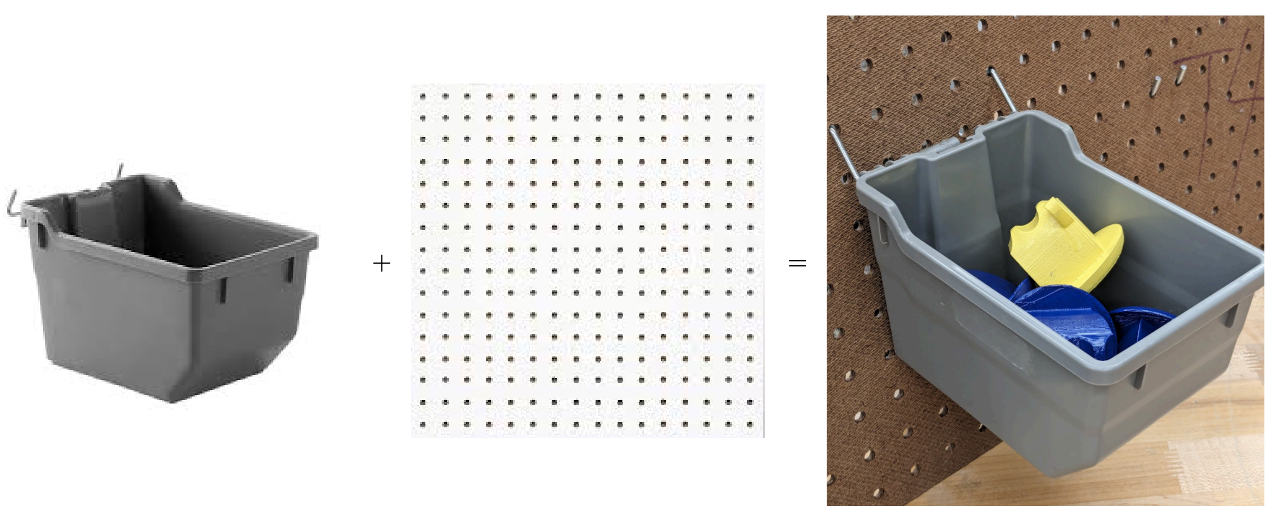
Pegboard Assembly:

1) Use L-Bracket to screw pegboard to the ping-pong table



2) Attach 10 hooks to pegboard with two at every two rows:

3) Attach bucket to the back of the pegboard



Ping Pong Table Assembly:

1) Drill holes in table and attach metal blocks underneath

   a) 

2) Use hook system to connect and attach tables together

   a)