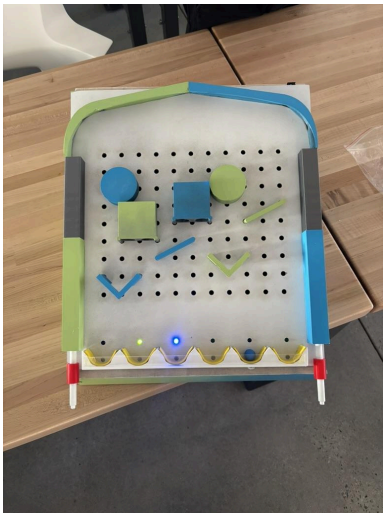
Northeastern University
College of Engineering

Cornerstone of Engineering II
Term 2

Peg Lab Plinko!



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Group 3

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Report Submitted: 4/20/25

Abstract

The core challenge of our project addressed the difficulties in teaching a class full of unique personalities who all had varying bases of knowledge and understanding. The primary project users were fourth and fifth graders who expected an interactive, engaging toy that was transformative and applicable to their learning. Our toy needed to illustrate physics and engineering concepts that were relevant to the California Common Core Math Standards and in-class learning. Through successful planning and design, the toy aided the teacher in the classroom by encouraging the 4th and 5th graders to improve problem solving and strategic thinking through competitive play. The goal was for students to learn to overcome challenges and use their problem solving skills to come up with strategies with a goal in mind. The product that was developed to solve the problem was the game *Peg Lab Plinko!*. It involves a user arranging pegs on an inclined board and then, using a spring loaded launcher, launch the ball into the pegs and try to score in one of the wells at the bottom of the board. Overall, *Peg Lab Plinko!* resulted in high interactive engagement, strategic play, and encouraged collaboration among students. This qualitative data was collected purely from observation. Students were successfully able to apply concepts of physics and engineering from planning different routes using peg placement and launching the ball with different trajectories to reach their respective targets. We noticed that the students were able to understand the game in a short amount of time and quickly became comfortable with the competitive aspect of the game. The game was extremely durable during both showcases with only two pegs snapping from aggressive handling.

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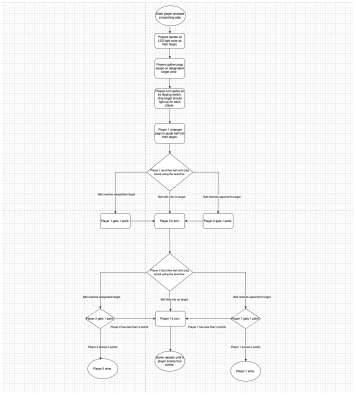
Final Design Documentation

(Ethan Lazar)

User Experience

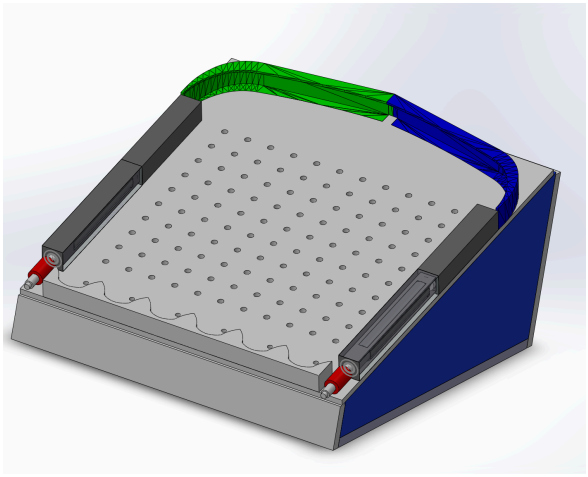
The final prototype of *Peg Lab Plinko!* is designed to deliver an engaging, intuitive, and competitive learning experience for elementary school students, specifically for fourth and fifth grader students. The core mechanic of the toy includes launching a ball from a spring power mechanism and observing its path through a field of different shaped pegs. Students arrange the pegs on the board to develop strategic paths that increase their chances of scoring, promoting problem solving skills and critical thinking.

The intended way this game should be played is as follows. Users apparch the board and are split into two teams, blue and green. Both teams take turns placing 4 pegs in total onto the board. The game is then turned on and one blue and one green LED above the wells light up. Each team takes a turn and uses the spring loaded launcher to launch their balls onto the board. The ball travels down and into one of the six wells at the bottom of the board. If the ball lands in the well with no LED light up no points are scored. If a ball lands in a well with a lit up LED of the same color the team that launched that ball scores a point. If the ball lands in a well of the opposite color where the LED is lit up the other team scores. If the ball gets stuck anywhere on the board the team is able to relaunch the ball. Once both teams have launched their balls they each are given the option to move or replace one of the pegs that have been placed with there only being a maximum of four pegs of each color on the board at a time. The game ends when one team has scored four points.



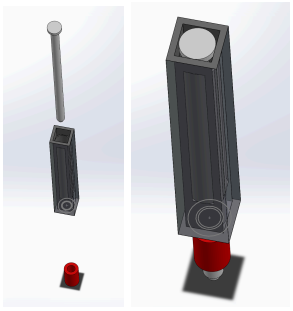
Final Design Description

The final prototype of *Peg Lab Plinko!* consists of a frame, two spring launchers and electronics for the automation of game play. The frame is made out of half inch thick plywood and consists of a base, two side pieces, and a front support for the board. There is also a door in the rear so that the electronics can be accessed. On top of this frame sits the playing surface that sits at a 20 degree angle to make sure the balls roll down it. The board also has a 10 x 11 grid of holes that are a quarter inch in diameter. These holes are where the user slots in the different pegs. On each side of this frame sit the two spring launchers. At the bottom of the pegboard is the scoring zone. This is made up of six wells that are each padded with foam and there is acrylic in front of them to keep the balls bouncing or falling out once they are in the wells. At the top of the board there are two tubes that are used to make sure the ball comes out straight from the launchers and there are also two barriers to keep the ball from flying off the board.



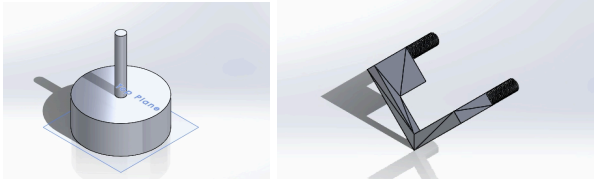
[Fig.4, Appendix A]

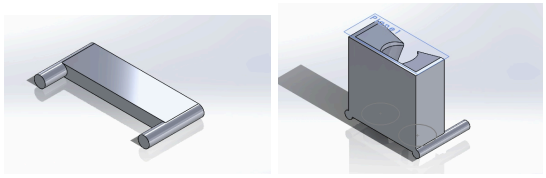
The spring launchers on the side are made up of three parts. There is the main tube which houses the spring, the shaft which is used to launch the ball and the handle which is there so that the user is able to successfully grip and pull the shaft to launch the ball. The spring sits inside the housing while the shaft pokes out through the bottom.



[Fig. 5 & 6, Appendix A]

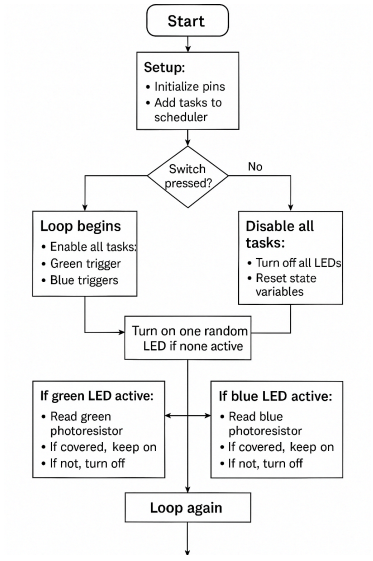
The pegs that are inserted into the board come in many different shapes and sizes. All of them, no matter which type they are, each have at least one cylinder on the back that is about 0.23”- 0.24” in diameter. There are six different types of pegs the player can choose from. There are two pegs with cylinders on the ends, a hopper, a ramp, and two different types of 50/50 splitters.

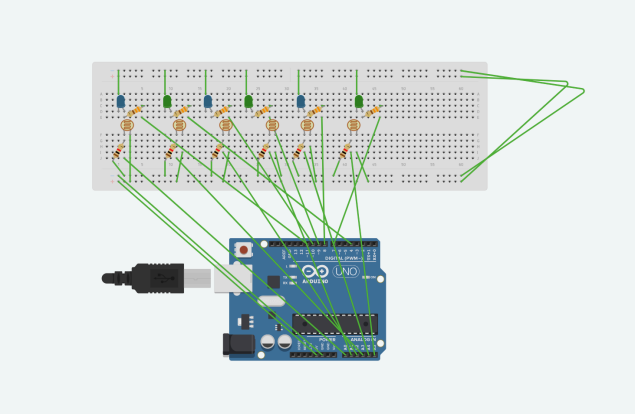




[Fig. 7, 8, 9, & 10, Appendix A]

The electrical system indeed in this game uses LEDs (three blue and three green), photoresistors, a SparkFun RedBoard(depicted as an arduino uno in wire diagrams), and a slide switch. The LEDs are wired to the digital pins on the RedBoard allowing them to have data written to them. The photoresistors are wired into the analog pins on the board so that it can read the voltage that is going across them. To begin the game only starts if the switch has been flipped. If the switch has been flipped one of the green lights and one of the blue lights will turn on. If a voltage drop is detected in the corresponding photoresistor the current light will turn off and it will switch to one of a new color. The code uses a scheduler to make sure that the voltage of all the photoresistors can be checked at the same time.





[Fig. 1, Appendix D]

The process of constructing this prototype involved several different methods. The frame was constructed using the tools in the wood shop. The board with the holes in it were laser cut and so was the acrylic panel. Everything else was 3d printed so that it could be made in a fast and efficient manner.

Results

(Chloe Flores)

There were two separate showcases to evaluate the final design including the early showcase on April 8th, and the final showcase on April 11th. To record qualitative data, observations were organized into different categories. The categories included behavior, engagement, strategic play, durability, improvements, scoring, and notable comments.



(Appendix E)

It was observed that the students enjoyed verbalizing their thought processes and strategies for planning the route of the ball to their targets. Another common behavior among the students was reacting to the outcome of the ball's trajectory. For example, if the ball landed in the target, the students would squeal and verbalize their excitement. If the ball didn't reach their target or landed in an opponent's target, they would show their disappointment and were eager to try again. We noticed the students enjoyed repetitively pulling the spring contraption and the aspect of adjusting the different pegs. Some notable comments we got from the students and professor were, "This is the best game here", "Your game definitely passed the durability test", and "This was a very fun game". At the end of the final showcase, the 4th and 5th grade teacher asked if our team could donate the toy to the classroom because she said our toy seemed to be the biggest hit out of the rest of the toys in the classroom. We also noticed that the students didn't want to leave our station or leave once the showcase ended because they wanted to continue playing our game. See appendix B for all qualitative data summarized in a tabular format.



(Appendix E)

Overall, the game stayed intact and only two pegs broke during the early showcase from misuse. Some negatives we noticed were that some students frequently asked what the score was and who was winning, and some groups took longer to plan out their peg routes which gave them less time to shoot and score points. A result we weren't expecting was that students were collaborating a lot among their team for strategy purposes as well as making competitive comments towards the opposing teams. When comparing *Peg Lab Plinko!* to the other games in the room during both showcases, we realized that our game was inviting, kid friendly, and could be played by a broad range of students intellectually and of different ages. The professor's son, who is in kindergarten, was able to understand and play the game with the older students in 4th and 5th grade. After speaking to a fellow engineer

from a game that involved mathematical applications, they noticed that there was a bigger learning curve for the students from the public school than the private school and it negatively affected the user experience.

Discussion/Analysis

(Archer Huang)

Some of the constraints to this final design were that it had to conform to US safety guidelines for a toy, had to cost less than $100, and had to be original. In terms of the safety guidelines, extensive research was done to ensure that our team knew the guidelines, and thus the toy conforms to these guidelines. The only possibility of danger would be choking hazards in the balls, or the spring being too strong and possibly pinching or bruising stray fingers. In our testing, this never happened, and at the showcase, no user was harmed by the spring or ball. The portability of the toy is much harder to defend, as it is not the lightest nor smallest toy to transport. Although it is manageable, it is slightly clunky. The overall footprint of the final design was increased from previous prototypes to allow for a shallower slope angle of the board, for engagement's sake, but it did sacrifice overall spacing size. But, this is not a huge issue because again, it is still a manageable size and weight for most middle school-aged users to move.

The cost of the toy was well within the $100 budget, costing $47.08 in reference to Appendix F. The overall value of the toy is higher, but many of the materials used by our team either already had or were able to obtain for free. The originality of the toy is slightly lacking. *Peg Lab Plinko!* takes inspiration from several other contraptions and ideas, such as pinball and plinko. Although it would not be very hard to find toys similar to our final design, *Peg Lab Plinko!* still has many unique aspects, such as the 20° slope or the combination of spring launcher and free pegs. This kept the design simple and relatable, both good for the overall engagement and enjoyment of the toy.

When looking at the design requirements for *Peg Lab Plinko!,* the toy needed to be not only interactive and teach students STEM-based concepts, but also look aesthetically appealing and engaging. From an engineering perspective, our toy had to incorporate digital or mechanical components and parts from Sparkfun Arduino kits. As a bonus, it also needed an auto-reset ability, as well as 3D printed or laser-cut parts.

Our final design met all of these design requirements. From an engineering point of view, our toy incorporated not only an on and off switch, but also automatically shifted lights, giving it the auto-reset optional requirement. It also used a RedBoard, jumper wires, a breadboard, photoresistors, and LED bulbs from the Sparkfun kits. When looking at how well it taught students STEM concepts, it is important to remember that *Peg Lab Plinko!* originally aimed to introduce students to the Engineering and Science aspects of STEM, as stated in our problem statement. At first glance, it was remarked by fellow engineers that there didn’t seem to be any real STEM learning when playing the game. But, when observing the students interacting with the toy, it was obvious that STEM concepts were learned by implementing physics and structural planning. The students had to plan a route for the ball to land in the target, which is a key aspect of structural engineering and problem-solving. Physical concepts, such as spring energy and gravity, were displayed in the launcher and in tracking the ball down as it bounced and was altered by pegs.

The success of the final design from an aesthetic standpoint is subjective. The colors we chose for the two teams were blue and green. The design and layout are very basic, which can work against the game. On top of this, there were grey parts on the board, which stood out and very easily could have been painted over to make the game more uniform and pleasing to the eye. But, there is also no polarizing or controversial color scheme or designs on the game, which makes it hard to say that the game is unpolished. The wires were successfully covered, with an easy-to-access back door where curious kids can still look into the brains of the game and all of the wiring. The color scheme did receive a complaint from one student who was colorblind. This is definitely a problem, as the toy is supposed to be inclusive to all, yet the colors could provide an issue to students with visual disabilities. If done again, research would go into this to determine the best colors that conflict the least with color blindness.

The engagement of *Peg Lab Plinko!* was very high, as indicated by our results in Appendix B. Students after the showcase approached our team, remarking how it was the 'best game [they] played', and how much they enjoyed *Peg Lab Plinko!*. On top of this, the teacher asked our team to donate the toy to the classroom, which is qualitative evidence of how successful and engaging *Peg Lab Plinko!* was. Yet, when observing the groups of students playing with the toy, there was the occasional student who looked completely uninterested in the game, or was unable to get as many turns as some of the other students. This indicates that although the final design for *Peg Lab Plinko!* did have aspects that were engaging, it did not have perfect engagement, and there is definitely still room to improve that aspect of *Peg Lab Plinko!*.

The bonus criterion objectives that our design met included using 3D printed parts and lasercut parts, which our design met, and also parts from the campus Reuse Depot. Our design included multiple Reuse Depot parts, such as anti-slip pads on the bottom, as well as a peg bag to hold all of the pegs. The bag was convenient, as it was velcro sealable and fit perfectly into the back of the toy without intruding on the wiring. Unfortunately, there were also flaws seen in these implementations. Not only were the grip pads not fully effective, as students pulling on the spring launchers still moved the entire board and were forced to hold the base while pulling, but the peg bag also barely fit all of the pegs and had a slight smell to it. Thus, although the Reuse Depot component was met and was useful to our toy, there may have been better options or improvements that we could have made for a better grip and a better storage method.

As discussed in our results section, there were multiple observations in terms of the gameplay and overall structure of the game that can be improved upon. This includes pace of play, scoring, and scorekeeping. For example, to counteract slow play, a timer can be added with a penalty for not placing pegs, such as the loss of a peg for that round. Such improvements would have increased engagement and overall satisfaction with the toy amongst its users. Another issue was the lack of ability to keep score, and relying on the users to track it themselves. A fix would be to automate this process using screens, which our team had the capability to do, but due to time, was unable to fully implement and thus scrapped the idea from the final design. Again, this improvement would not only make the game easier to play, but would utilize the user's age and fascination with screens to the toy's advantage.

Major strengths observed in the toy when being used were the high levels of engagement and pleasure users showed, as well as the desire to continue playing and come back to the game at the end of the showcase. Another strength was the variety of pegs created and the creativity users displayed when placing the pegs. Many pegs ended up being placed upside down or sideways from the intended design, which led to creative strategies of

differing success. The strength in this was that it heightened the structural planning aspect of engineering and problem-solving. Another strength was the simplicity of the rules. Explaining the rules took less than a minute, and there were few questions pertaining to the rules and gameplay. This was good for engagement, as it lowered frustration amongst the users.

Some of the weaknesses included the immense noise when the spring launcher slammed into the capsule and the ball shot off. This was counteracted by adding tape as a noise damper to the top of the launcher handle, but it didn't fully dampen the noise, and some users still jumped at the loud noise. Another weakness was the occasional accidental light change. Users would either cover the photoresistor or drop a ball onto the photoresistor, superficially triggering a light change when a light change should not have happened, and thus disrupting the planned peg route already on the board.

Conclusion

(Andrew Enkhsaikhan)

Peg Lab Plinko! met every requirement laid out at the project's start. We were able to design and create a toy that was under $100 (at $47.08) and followed all safety guidelines and regulations with rounded parts, shielded springs. The project also demonstrated both mechanical and electronics elements with use of a SparkFun Redboard, sensors, and LEDs. The toy was tested and found to have high student engagement, repeated play, and strategic discussion (Appendix B). This modular peg field delivered both complexity in mechanics but also high engagement and use of strategy in order to win. Students easily grasped the ruleset and were able to start mastering the game within a few minutes of play. During these sessions the toy experienced minimal failure, with only expected wear and tear on the most physical parts of the launcher, the electrical system/sensors worked with little to no errors and reset on demand. The toy was highly accessible to even the shortest of students, with a 20 degree low slope and easily accessible side launchers. The toy met our goals of being educationally stimulating and forced players to create strategies in order to win. Final issues include the accessibility factor for the colour-blind, lack of a score-keeping system, and sensor failure to detect, all of which are documented in Recommendations. These failures are minimal and do not interfere with the toy's overall success in meeting goals, constraints, and educational criteria.

Recommendations

(Andrew Enkhsaikhan)

Given more time and resources, many aspects could be improved upon within the design. During testing many physical components showed signs of wear from use by students. The spring launching mechanism (the main form of physical interaction by user) experienced high stress loads from the pulling motion, the E6000 glue used to secure the red pulling tab onto the shaft of the launcher started to slide off after extended use. This can be accounted for and amended by creating a slight cavity in the shaft where two halves of a tab can be secured physically rather than just glued by an adhesive. The same can be applied for all parts during assembly, the entire wooden frame should have cutouts and extrusions to be assembled more precisely. During assembly of the final design, slight deviations in measurements or assembly in parts by hand caused slight mismatched tolerances and a poorly finished build quality. This was especially true for the rear door which was placed using a door hinge, but had to be slightly offset from the base to account for the swinging action of the door. The launcher mechanism

should also be revised to include a weaker spring that has a more predictable power curve when launching (current spring has too high of a tension) as well as a hole that allows for easier loading of the ball after collection (currently the ball is loaded from top of the launcher tube).

During our final testing, we found that using a heavier marble (instead of our 3D printed ball) also helped us achieve a more predictable launcher.

Andrew Enkhsaikhan

1.1 Lessons Learned

Contributions

My contributions to this project included the physical assembly of the original prototype, design and implementation of the final spring launcher and collection system, and painting the final product for design. The original physical prototype made of cardboard was fully assembled by me using a combination of a hot glue gun and regular Gorilla Glue. With our final design, I was in charge of fully designing and 3D printing the spring launcher system. I used Solidworks to create the part files for the original launcher and lower collection hopper, iterating through many designs of launchers which would either not launch strong enough or fail to be predictable. Using Solidworks I measured and translated our original prototype into individual part files, this included all base platforms, ramps, launchers, and face of the toy.

Resources

Our group was able to meet budget requirements quite well. We only spent around $40 of the total $100 budget. I personally spent a lot of time travelling to various stores in the area, including Ace Hardware's and Home Depots to gather the required materials and tools (springs, paint, glue, etc.). Similar to other group members I contributed large amounts of time at the engineering makerspace working on the project and in group meetings. With an exception to a couple of meetings, I attended and contributed to meetings, pitching my own ideas to the design process, influencing the end product.

Reflections on Learning

This project has strung together a large number of engineering skill sets into one cohesive end product. I was able to use skills I already had and apply them more fully: soldering, 3D printing, woodworking, and assembly. This project has helped me understand the designing process behind products on the market today and what it takes for them to be sold publicly. This combination of skills can now be applied in future projects which I may encounter at Northeastern University or in the workforce.

Reflections on Working in a Team

The largest aspect of this project that was new to me was the teamwork aspect. This project was one of the most involved teamwork projects I have completed to this day. It required careful planning of meetings and details on the project, including exact measurements, tolerances, layouts, and materials. Communication was key and being quick to respond to questions throughout the day was something I worked on as the project progressed. Being able to quickly meet and organize a session to forward the project was also key.

Chloe Flores

1.2 LESSONS Learned

Contributions

Between milestones 3-5, I made various contributions depending on my role for each milestone. Overall, throughout all milestones, I did most of the technical work relating to documentation such as taking almost all of the progress photos and consistently updating the design notebook during or after each meeting (see Appendix E). I also helped with figuring out dimensions and the design of each prototype through consistent discussion with my teammates.

In milestone 3, I contributed to the prototype by laser cutting the slots for the first version of the prototype and assembling the rails and slots using hot glue, I made markings and measurements for the slot placements and holes for the thin slab of wood, and I helped gather materials and setup the spray painting station using the brown paper. I also researched electronic components for the CAD design, created a flowchart, and began working on the wire diagram. See Appendix E: Milestone 3.

In milestone 4, I was assigned project manager in which I planned our almost daily team meetings and sent out reminders, made sure the team was on track, consistently updated all aspects of the resource management and design notebook, and presented our progress at the end of the milestone. For the manufacturing process of the first prototype, I assembled all 3D printed pieces on the face of the game using hot glue. As far as the MCCS visit, I took detailed notes and made observations during the visit, listened to feedback from the students and teacher, I made a survey for students to fill out, and I revised and filled out our feedback table based on the feedback after the visit. For the second prototype, I helped test out different angles that were efficient for the ball to glide, I lended Archer a hand with drilling on the hinges and adding wood filler, and I helped scrape off excess filament of the 3D prints. Finally, before my final presentation, I made major updates to my original flowchart. See Appendix E: Milestone 4 for reference.

In milestone 5, I recorded the demo video, helped present and explain the toy during the showcase, and took detailed notes during the early and final showcase. Using those notes, I created a table of our observations (Appendix B).

Resources

Our group successfully met the $100 budget since we only spent $47.08 (Appendix F). For the electronics, I donated parts from my SparkFun kit like the redboard, jumper wires, photoresistor, and LEDs. From milestone 1-4, I devoted a total of 65.75 hours (Appendix G). This experience has taught me that resource management is very important because losing track of the money spent on a project can easily lead to overspending if not planned properly. It has also been helpful in keeping track of how many hours each team member has devoted to the project to make sure the work is evenly split.

Reflections on Learning

Even though I had experience practicing the engineering design process with the robot project last semester, I feel as though this project enforced the process even more so. This project focused on a real world application so it helped me develop my research skills by conducting intensive background research on the STEM toy market and stakeholders. During the designing process, I was able to get trained in laser cutting and 3D printing

which I am proud of and it will benefit me in future courses.

Throughout this project, I gained the skill of consistently taking progress photos whenever our team made major progress during our meetings. This helped provide us material for the design notebook, presentations, and give us references to reflect back on.

Reflections on Working in a Team

After working on this project, I believe I strengthened my team working skills by learning to interact with team members of different personalities and strengths. I learned to develop more patience when things didn't go as planned and I learned the importance of communication. When our team didn't communicate early in the project, it created confusion and sometimes frustration. We tried to overcome that obstacle by communicating more in later milestones. An aspect of teamwork that I need to work on is keeping a collected and positive attitude during stressful times. The stress that came with working close to the deadline didn't let me think with a clear mind and it would cause me to worry instead of taking initiative.

My leadership style consists of maximizing productivity by acknowledging and assigning tasks based on each team member's strengths. I also try to foster a lot of communication and keep everyone on track by having a list of tasks for each of our meetings. To strengthen our team dynamic beyond the work environment, I tried to balance light hearted conversations with serious ones during our meetings. As far as being managed, I followed the instructions and tasks assigned by each project manager and came to meetings prepared when they assigned work. To overcome adversity as a team, we acknowledged and discussed the conflict, tried direct confrontation, and in extreme cases, consulted our professor.

I think my biggest asset to my team was my organizational and time management skills especially when it came to being project manager in milestone 4. We were able to get a lot of work done during this milestone because I made sure to plan for failures along the way and start our work early. If I could go back to the beginning of the semester and start over again, I would have made sure to start our work earlier and try to plan more team meetings to improve our team dynamic early on and grow closer as a team. If we had more time to work on the project, it would be helpful to add a scoreboard and find more reliable photoresistors since they are prone to breaking.

Archer Huang

1.3 LESSONS Learned

Contributions

In Milestone 3, I had to use the woodshop to cut and piece together the base frame for our toy. In our original prototype for Milestone 4, I also designed the spring launchers. By the end of Milestone 4, I had to use the laser cutter and home tools to redesign the base and re-screw and glue the base together. I also used the laser cutter to cut the face of the board, as well as collaborating with my team to redesign the number of holes and wells on the face. I laser cut a 0.5-inch by 12-inch acrylic cover that sits over the wells to ensure the ball doesn't bounce outwards. I also bought foam for the bottom of the wells to prevent the balls from bouncing out as much, as well as blue and green spray paint, and assisted Andrew in painting all of our pegs and the base. In Milestone 4, I also designed a guide rail for the top of our toy for the ball to track along in SolidWorks, and used the 3D printer to print out two of these pieces. Also using SolidWorks, I designed and printed an updated splitter peg and cylindrical pegs, as well as printing out the balls. The Reuse Depot was also a resource for our team, as I went there to get grippy pads for the bottom of the toy and a pouch to organize all of our pegs and balls.

Resources

Our group was well within the confines of the project budget. We spent $47.08 out of the $100 budget. I personally bought two bottles of spray paint, the green and blue, and also the blue tape and masking paper that we used to spray paint with. I also bought the hinge for the back door and the marbles, which we ended up not using. Other components that I already had that I donated to our group included velcro strips, as seen in Appendix F, a battery pack, a photoresistor from our SparkFun kits, and various wires. I devoted a total of 66.25 hours from Milestone 1 to Milestone 5, and a breakdown can be seen in Appendix G. My understanding of resource management has been expanded because I now realize that it is important not only to have excess in case of failure, but also to order parts early so that there is still time to test and adapt and evolve the prototype.

Reflections on Learning

From this project, not only did I learn how to 3D print, laser cut, and use various tools in the woodshop, but I also bettered my understanding of teamwork, SolidWorks, and meeting and setting deadlines. I am especially proud of my newfound woodworking experience, as I enjoyed using the woodshop and can now use multiple tools such as the miter saw and table saw for future projects and implementations. I also learned 3D printing software, which I think will help me greatly in the future in my intended career for modeling and prototyping.

This entire project and process has also bettered my ability to document and made me realize how useful and important it is to keep an organized, insightful documentation of progress. The Design Notebook was key for storing progress updates and showing a timeline of how the toy came along, and will be a skill that I will be able to take with me into my future.

Reflections on Working in a Team

Although I have prior experience working in a team and being a team leader, this project gave me insight into how teams work in an engineering setting. This project made me improve my documentation skills and ensured that everyone on the team had access and insight

into the work that I was working on. Our team had to overcome time conflicts and inconsistency from fellow teammates. I personally can be better at giving feedback and knowing when to offer help to team members.

I think that my leadership style was inclusive and soft, as I tried to listen to every opinion and suggestion that was made. I think that I could have done a better job at enforcing deadlines and checking in with my team to make sure that every aspect of what needed to be accomplished was being accomplished at a satisfactory level. I think my ability to be managed was high, as I listened and followed what the PM said and did to the best of my ability on every task that was assigned to me. My biggest asset for the team was my timeliness and consistency. I didn't miss a single team meeting and was also able to complete all assigned tasks on time.

If we had more time on this project, I would have liked to have implemented an electronic scoreboard, as well as a better spring that wasn't nearly as powerful as the one that we used. Going back to the start of the semester, I don't think I would change much, except maybe volunteering to be a project manager during M3 or M4 to alleviate that pressure from my fellow group mates, as I felt a little bad for them as they stressed during those two milestones where I felt the milestone I managed was much simpler.

Ethan Lazar

1.4 Lessons Learned.

Contributions

My contribution to the project was being in charge of the electronics. I was responsible for doing all the wiring and coding for the toy. This included me procuring the electronics and religiously resting them to make sure they worked most of the time. Another contribution to the project was I was in charge of making the CAD assemblies. I gathered all the files created by my team members and I put them together and created the exploded views.

Resources

Our group was well under the budget of $100 dollars coming in at $47.08. I personally contributed most of the wiring, the LEDs, and the RedBoard for the project. I also bought the photoresistors we used for the project. Over the course of all five milestones I ended up contributing at least 65 hours between milestones one and five.

Reflections on Learning

This project helped me gain a better understanding of the engineering design process. Before starting this project I only understood the process conceptually, but doing this project allowed me to experience how the process is actually applied in the real world. The project also taught me the importance of documentation. Throughout this project I was given the task of filling out the design notebook. This allowed me to experience how one might document their process and how they could be used to explain a project to others. The milestone format for this project helped me learn more about how the engineering process is broken down into steps and does not just happen all at once. Along with this I learned about how to use the makerspace. I did not just learn how to use the tools in the makerspace , but how to respect them and others who are using them.The stuff I learned does not just apply to this class but also to other classes I take down the line and even my career. This project gave me some insight into what a professional engineering workflow may look like. In all, I feel that this project was a very important educational experience that prepared me for the world of engineering that I am about to enter.

Reflections on Working in a Team

This project gave the opportunity to work in a team of engineers. I was able to learn how to collaborate with people. Also, I learned about the difficulties of working in a team. I learned how to compensate for other people when they do not fully contribute to the project. I feel that I was also able to be effectively managed as I understood my responsibilities in the group and did the work assigned to me. Also, when I was manager I learned how to effectively distribute and how to efficiently run a team. My biggest asset to the team was my putally and hard work ethic. This allowed me to complete tasks in a timely manner and help others when they could not complete their tasks in a timely manner.

Author Biographies

Andrew Enkhsaikhan was born in Los Angeles, California in 2005. He graduated from Troy High School in 2023 and is currently pursuing a bachelor's degree in Mechanical Engineering at Northeastern University in Boston, Massachusetts.

In 2024, he programmed a fully autonomous Arduino robot that could navigate a maze on the floor. His research interests include material science, RF engineering, and electrical engineering.

Archer Huang was born in Redwood City, California, in 2006. He received his highschool diploma from Sequoia High School, Redwood City, in 2024, and the IB Diploma from Sequoia High School, Redwood City, CA, in 2024. He is currently studying civil engineering at Northeastern University, Boston, MA.

In 2023, he wrote a 3700 word research paper on the effects of global warming in China and possible solutions in use. He also worked in 2024 with a partner to build and program a robot to navigate various mazes. His current research interests include sustainability, structural design and planning, and mechanical physics.

Chloe Flores was born in New York City, in 2005. She graduated from Newark Academy in New Jersey with an IB diploma, in 2024. She is currently aiming to receive a B.S. in civil engineering and architectural studies from Northeastern University.

In the fall of 2024, she was located in London where she worked with a team to program and build a robot to complete several mazes. Her research interests include sustainable structures, adaptations to climate change, and tropical architecture.

Ms. Flores is currently a part of the NU Oakland volleyball club team.

Ethan Lazar was born in Philadelphia, PA in 2006. He graduated from Central High School in 2024 and is currently studying mechanical engineering at Northeastern University.

In the fall of 2024, he was located in London and worked on a fully autonomous maze solving robot. His research interests include aerodynamics, airframe structures, and aeronautical propulsion.

APPENDICES

(Chloe Flores, Archer Huang, Ethan Lazar)

APPENDIX A - FINAL AUTOCAD/SOLIDWORKS DRAWINGS

Figure 1. Exploded view of the assembly diagram

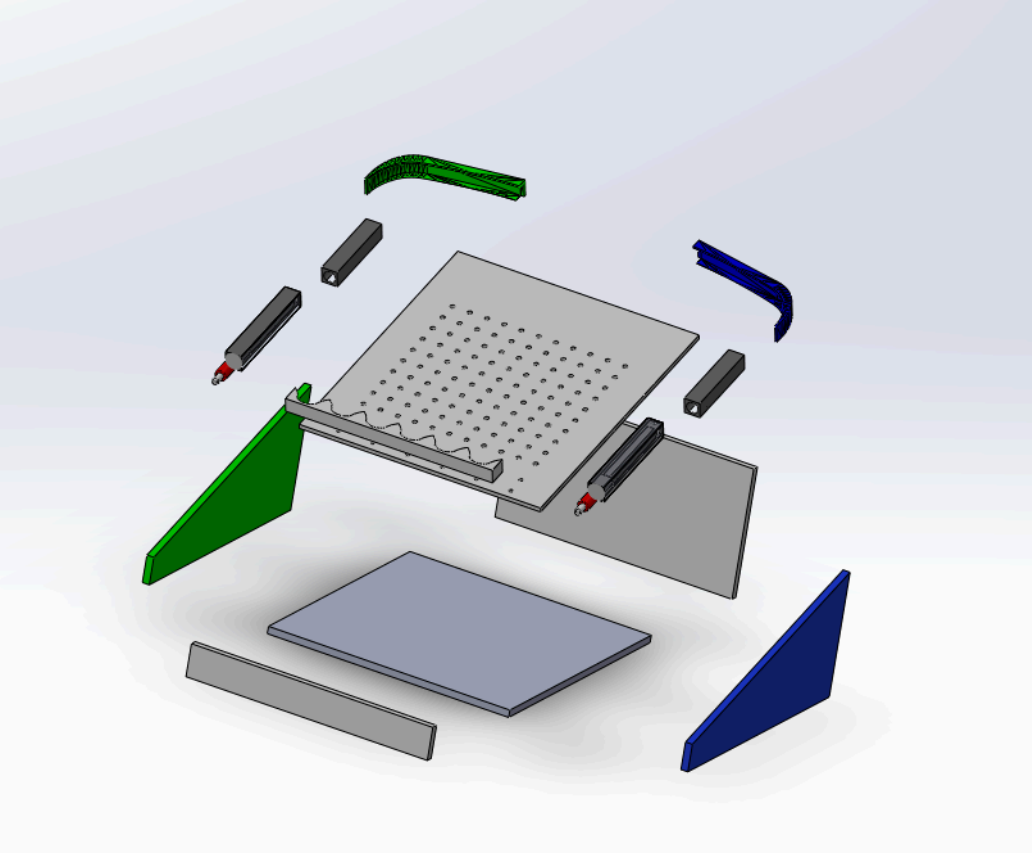
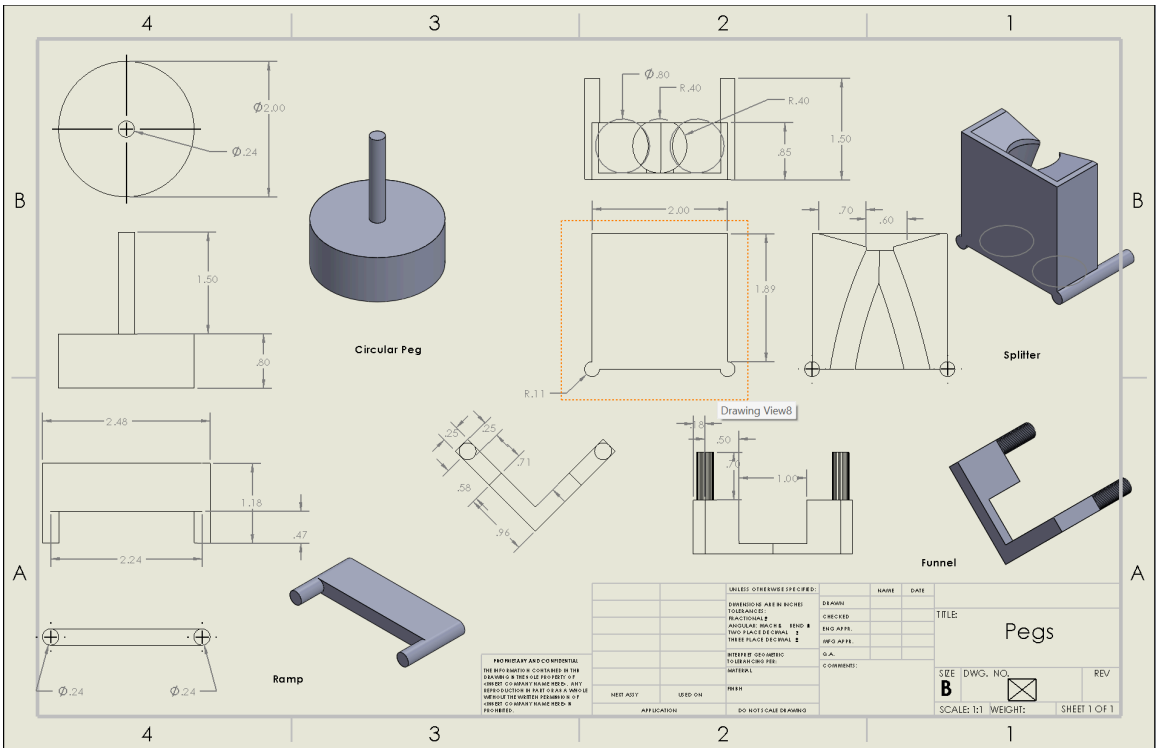


Figure 2 & 3. Drawings of the peg parts and spring launchers



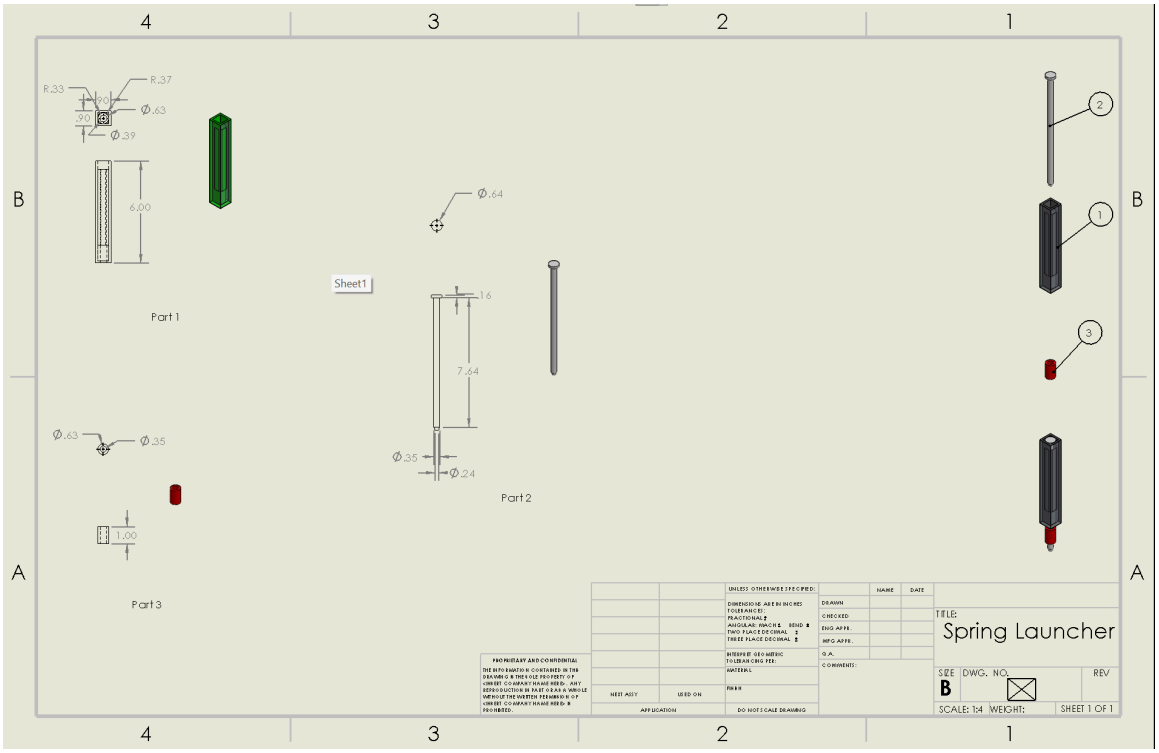


Figure 4. Assembly of *Peg Lab Plinko!*

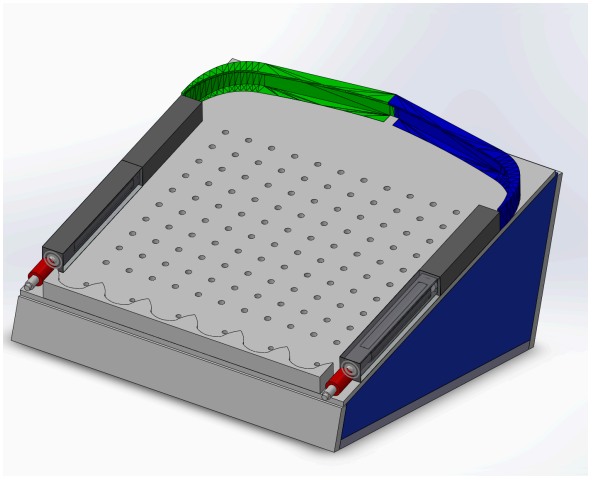
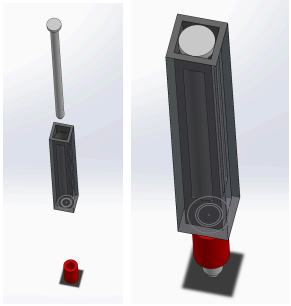
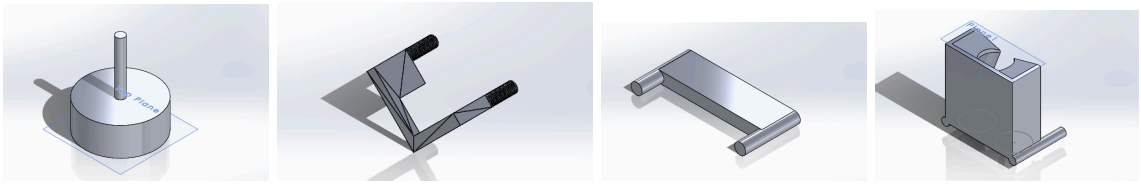


Figure 5, 6, 7 ,8 ,9 and 10. SolidWorks Parts of the spring launchers and the pegs





Appendix B – Product Testing Results

(Chloe Flores)

Table 1. Qualitative Data from Early and Final Showcase

Observation Criteria	*Early Showcase*	*Final Showcase*
Behavior	- Each group approached the toy differently with some being more aggressive and other groups being shy at first - Once each group got the hang of the toy after learning the rules, they became comfortable and very competitive - Some students came back to our station because they wanted to play again - Some students saw our game from a distance and wanted to play even though they weren't on our station	- Some teams took more time to plan routes than others - Minimal clarifying questions - All teams wanted to block other teams - Students familiar with the game from the initial visit to Mills were excited to play the final version - Reference picture helped students with orientation of pegs
Engagement	- Squealing and screaming if they scored - Sounds of disappointment when they scored for the other team or missed their target - Many smiles - Enjoyment of pulling spring contraption - Competitive banter among teams	- Enjoyment of pulling spring contraption - Arms waving in the air - Eager to touch different pieces of toy - Smiling - Light screams of enjoyment and failure - "Let's go!" "Yay" "Yes!" "I got a point!" - Competitive banter - Some students didn't want to leave the station
Strategic Play	- Verbal thought process for strategy - Teammates suggesting positioning of pegs - Pointing where the ball might fall - Constant moving of pegs	- Readjustment of pegs - Verbal thought process - Collaboration among team members - "We should move.." - You can tell the students were thinking hard about the routes - Physically helping each other place pegs - "If this fires into here…"
Durability	- Lasted entire class with only two pegs breaking from rough handling	- One students student enjoyed testing the full stretch of the contraption multiple times and its still working - No broken pieces

Scoring	- A couple teams were able to fully win scoring 4 points within 10 minutes - All groups and teams were able to score multiple points	- Able to score multiple times - One group was able to score back to back consistently and win - One group struggled to score
Notable Comments	- “This is the best game here” - “Your game definitely passed the durability test” - “This is cool”	- “This was a very fun game” - “That was fun” - “Can we donate your toy to the classroom? This game seemed to be the big hit”
Improvements	- Some groups of students needed reminders that they could move the pegs - Some students accidentally changed the target by hovering their finger over the target - Students were confused about the orientation of some pegs	- Method to keep track of score

Appendix C – Code Used in Project

```
// Stem Toy project
// Group 3 - Archer Huang, Ethan Lazar, Chloe Flores, Andrew
Enkhsaikhan
// This code turns on a blue and green LED, then waits for a
photoresistor to be covered
// to turn off the light and switch it to another randomly selected
LED.
// Uses the TaskScheduler library for non-blocking task management.
// (https://github.com/arkhipenko/TaskScheduler)

#include <TaskScheduler.h>  // Include the task scheduling library

Scheduler runner;  // Create a task scheduler

// Function declarations (task callbacks)
void green();       // Function to activate a green LED
void blue();        // Function to activate a blue LED
void checkGreen();  // Function to check green photoresistor status
void checkBlue();   // Function to check blue photoresistor status

// Task definitions: (interval in ms, repeat forever, callback
function)
Task taskGreenTrigger(100, TASK_FOREVER, &green);
Task taskBlueTrigger(100, TASK_FOREVER, &blue);
Task taskCheckGreen(50, TASK_FOREVER, &checkGreen);
Task taskCheckBlue(50, TASK_FOREVER, &checkBlue);

// Assign analog pins for photoresistors
const int photoGreen1 = A3;
const int photoBlue1  = A0;
const int photoGreen2 = A1;
const int photoBlue2  = A2;
const int photoGreen3 = A5;
const int photoBlue3  = A4;

// Assign digital pins for green and blue LEDs
const int ledGreen1 = 4;
const int ledBlue1  = 11;
const int ledGreen2 = 9;
const int ledBlue2  = 10;
```

```
const int ledGreen3 = 7;
const int ledBlue3  = 8;

// Pin for on/off switch
const int switchPin = 12;
bool systemEnabled = false;  // Keeps track of whether the system is
active

// Variables to track which LED is currently on (0 means none)
int activeGreenLED = 0;
int activeBlueLED = 0;

// Function to randomly turn on one of the green LEDs
void green() {
    if (activeGreenLED == 0) {  // Only choose a new LED if none are
currently on
        int randNum = random(1, 4);  // Pick random number between
1-3
        activeGreenLED = randNum;

        // Turn on the selected green LED
        switch (randNum) {
            case 1: digitalWrite(ledGreen1, HIGH); break;
            case 2: digitalWrite(ledGreen2, HIGH); break;
            case 3: digitalWrite(ledGreen3, HIGH); break;
        }
    }
}

// Function to randomly turn on one of the blue LEDs
void blue() {
    if (activeBlueLED == 0) {  // Only choose a new LED if none are
currently on
        int randNum = random(1, 4);  // Pick random number between
1-3
        activeBlueLED = randNum;

        // Turn on the selected blue LED
        switch (randNum) {
            case 1: digitalWrite(ledBlue1, HIGH); break;
            case 2: digitalWrite(ledBlue2, HIGH); break;
```

```
            case 3: digitalWrite(ledBlue3, HIGH); break;
        }
    }
}

// Function to check if the green photoresistor associated with the
active LED is covered
void checkGreen() {
    if (activeGreenLED == 0) return;  // No LED to check

    bool turnOff = false;
    // Determine whether the light level is high (i.e., photoresistor
is covered)
    switch (activeGreenLED) {
        case 1: turnOff = (analogRead(photoGreen1) > 850); break;
        case 2: turnOff = (analogRead(photoGreen2) > 800); break;
        case 3: turnOff = (analogRead(photoGreen3) > 900); break;
    }

    // If not covered (low light value), turn off the LED and reset
state
    if (!turnOff) {
        switch (activeGreenLED) {
            case 1: digitalWrite(ledGreen1, LOW); break;
            case 2: digitalWrite(ledGreen2, LOW); break;
            case 3: digitalWrite(ledGreen3, LOW); break;
        }
        activeGreenLED = 0;
    }
}

// Function to check if the blue photoresistor associated with the
active LED is covered
void checkBlue() {
    if (activeBlueLED == 0) return;  // No LED to check

    bool turnOff = false;
    // Determine whether the light level is high (i.e., photoresistor
is covered)
    switch (activeBlueLED) {
        case 1: turnOff = (analogRead(photoBlue1) > 800); break;
```

```
            case 2: turnOff = (analogRead(photoBlue2) > 800); break;
            case 3: turnOff = (analogRead(photoBlue3) > 900); break;
        }

        // If not covered (low light value), turn off the LED and reset
state
        if (!turnOff) {
            switch (activeBlueLED) {
                case 1: digitalWrite(ledBlue1, LOW); break;
                case 2: digitalWrite(ledBlue2, LOW); break;
                case 3: digitalWrite(ledBlue3, LOW); break;
            }
            activeBlueLED = 0;
        }
    }

    void setup() {
        Serial.begin(9600);  // Start serial monitor

        // Set all LED pins as outputs
        pinMode(ledGreen1, OUTPUT);
        pinMode(ledGreen2, OUTPUT);
        pinMode(ledGreen3, OUTPUT);
        pinMode(ledBlue1, OUTPUT);
        pinMode(ledBlue2, OUTPUT);
        pinMode(ledBlue3, OUTPUT);

        // Set switch pin with internal pull-up resistor
        pinMode(switchPin, INPUT_PULLUP);

        // Initialize random seed using analog noise
        randomSeed(analogRead(A0) + analogRead(A1) + analogRead(A2) +
    analogRead(A3));

        // Add tasks to the scheduler, but don't enable yet
        runner.addTask(taskGreenTrigger);
        runner.addTask(taskBlueTrigger);
        runner.addTask(taskCheckGreen);
        runner.addTask(taskCheckBlue);
    }
```

```
void loop() {
    // Check if switch is pressed (LOW = pressed due to pull-up
logic)
    bool switchState = digitalRead(switchPin) == LOW;

    if (switchState && !systemEnabled) {
        // Enable system if switch is pressed
        systemEnabled = true;
        taskGreenTrigger.enable();
        taskBlueTrigger.enable();
        taskCheckGreen.enable();
        taskCheckBlue.enable();
    } else if (!switchState && systemEnabled) {
        // Disable system if switch is released
        systemEnabled = false;
        taskGreenTrigger.disable();
        taskBlueTrigger.disable();
        taskCheckGreen.disable();
        taskCheckBlue.disable();

        // Turn off all LEDs
        digitalWrite(ledGreen1, LOW);
        digitalWrite(ledGreen2, LOW);
        digitalWrite(ledGreen3, LOW);
        digitalWrite(ledBlue1, LOW);
        digitalWrite(ledBlue2, LOW);
        digitalWrite(ledBlue3, LOW);

        // Reset active LED states
        activeGreenLED = 0;
        activeBlueLED = 0;
    }

    // Run scheduled tasks
    runner.execute();
}
```

Appendix D – Wire Diagrams for SparkFun Boards

**** Make it clear to what you are presenting – labels!

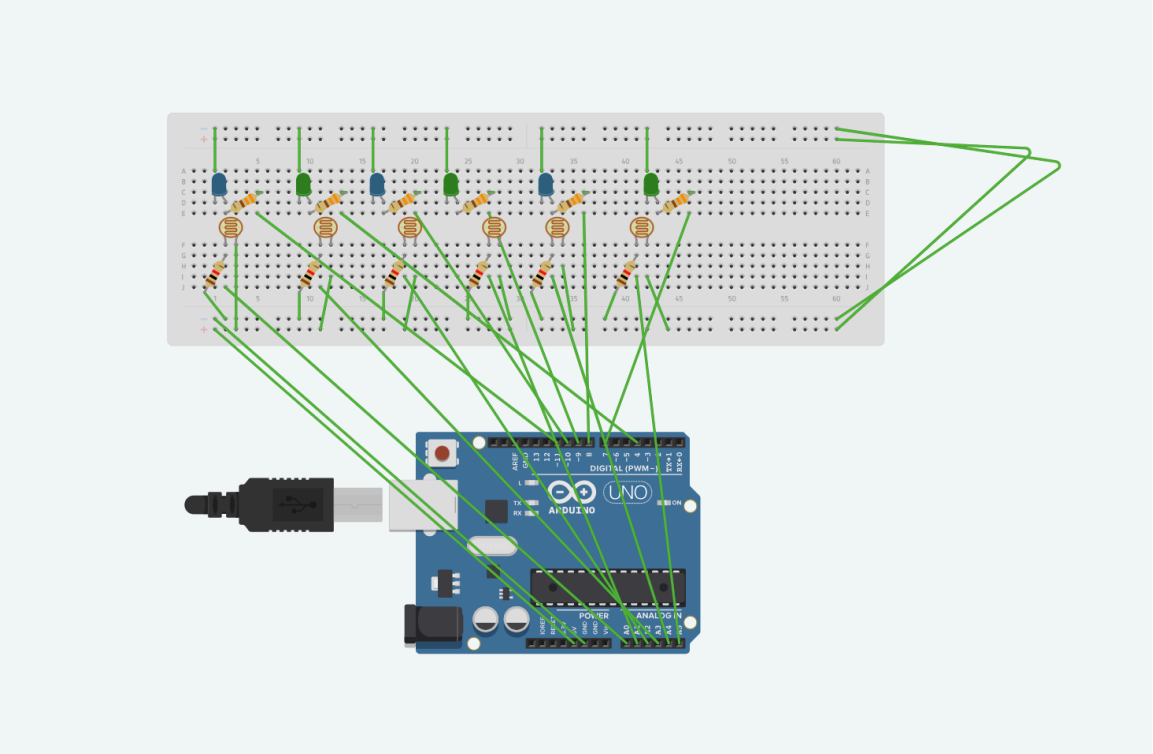


Figure 6. Wire Diagram of the photoresistors, LEDs, RedBoard, and wiring

Appendix E– Photo Log

(Chloe Flores)

Milestone 2

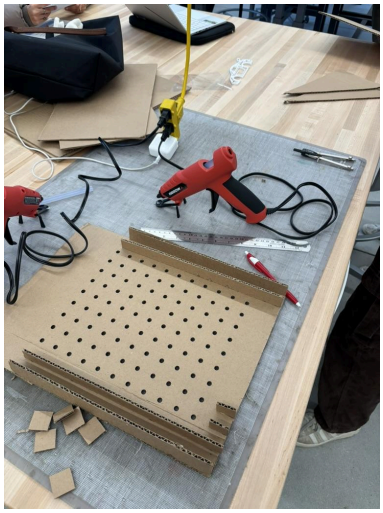


Figure 7. Milestone 2 building cardboard prototype.

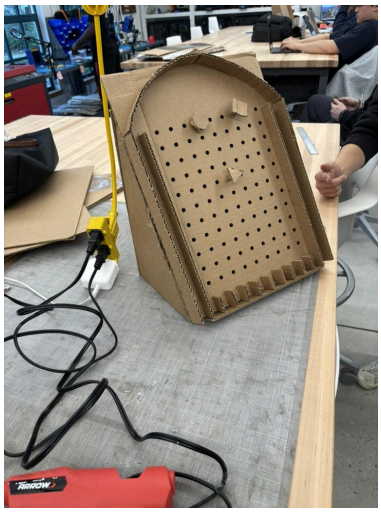


Figure 8. Milestone 2 completed cardboard prototype.

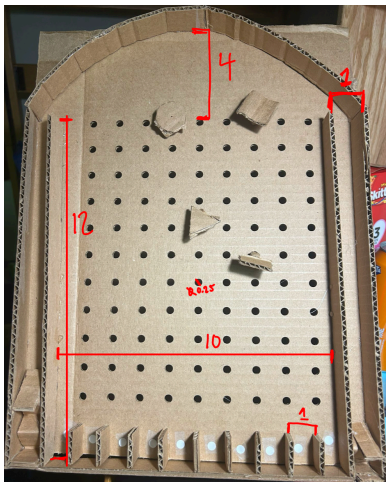


Figure 9. Milestone 2 dimensions of cardboard prototype.

MILESTONE 3

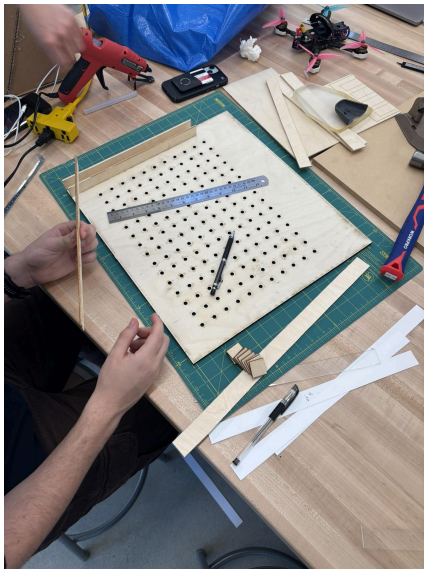


Figure 10. Milestone 3 building the first version of the actual prototype.

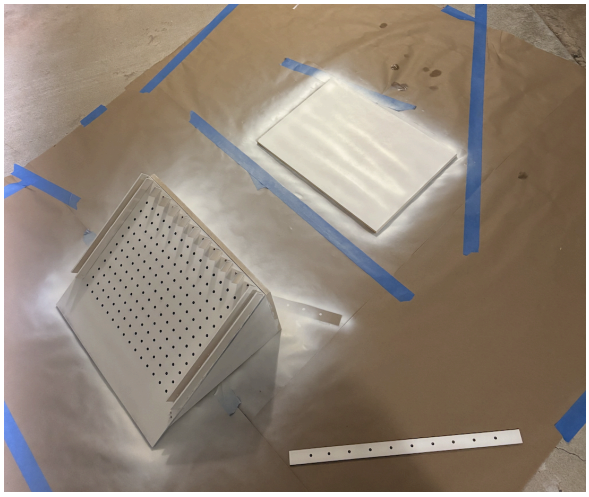


Figure 11. Milestone 3 spray painting first prototype.

MILESTONE 4



Figure 12. Milestone 4 completed prototype before MCCS visit.

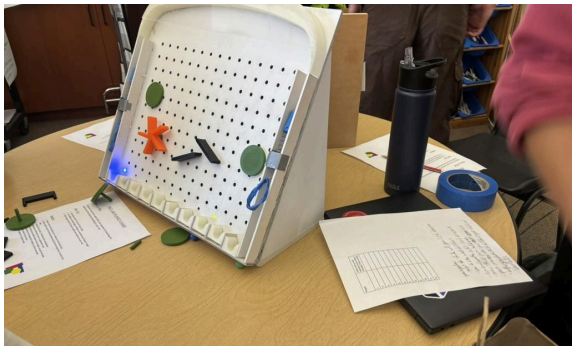


Figure 13. Milestone 4 MCCS students playing with the toy at the visit.

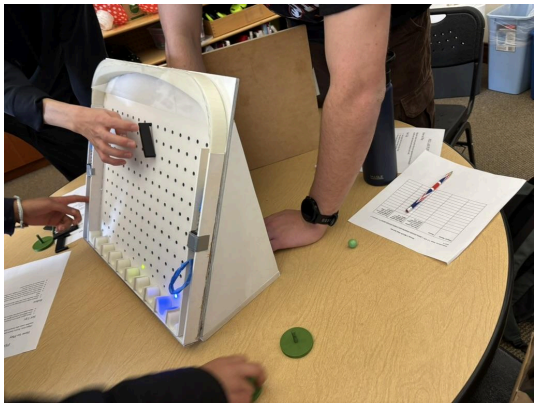


Figure 14. Milestone 4 MCCS students playing with the toy at the visit.



Figure 15. Milestone 4 designing second version of prototype based on feedback.

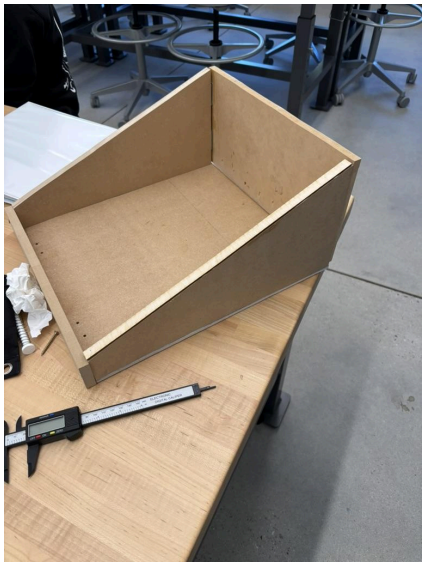


Figure 16. Milestone 4 building second version of prototype based on feedback.

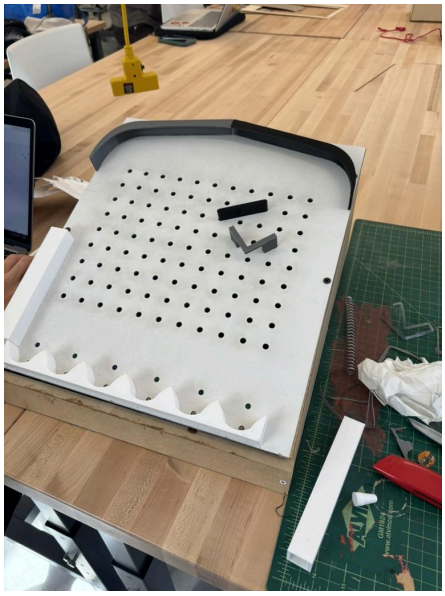


Figure 17. Milestone 4 assembling second version of prototype.



Figure 18. Milestone 4 spray painting second version of prototype.



Figure 19. Milestone 4 100% complete prototype from the side.



Figure 20. Milestone 4 100% complete prototype from the top.

MILESTONE 5



Figure 21. Milestone 5 100% MCCS students playing with the toy at the final showcase.



Figure 22. Milestone 5 100% MCCS students playing with the toy at the final showcase.

Appendix F – Final Budget

(Archer Huang)

Table 2. Budget breakdown of all the materials used

Item	Unit Value	Units	Qty	Value	Cost	Source
Marbles	$0.14	pk	50	$7.00	$7.00	5 Below
Comp Spring	$0.60	pk	6	$3.58	$3.58	Ace Hardware
Blue Tape	$6.98	ea	1	$6.98	$6.98	Home Depot
Masking Paper	$4.98	ea	1	$4.98	$4.98	Home Depot
Spray Paint	$5.98	ea	2	$11.96	$11.96	Home Depot
Photoresistors	$1.60	ea	6	$9.60	$9.60	SparkFun
Fullsize Breadboard	$6.50	ea	1	$6.50	$0.00	Makerspace
RedBoard	$29.95	ea	1	$29.95	$0.00	SparkFun Kits
Batteries	$0.72	ea	6	$4.32	$0.00	SparkFun Kits
Battery Holder	$2.10	ea	1	$2.10	$0.00	SparkFun Kits
Jumper Wires	N/A	N/A	N/A		$0.00	SparkFun Kits
LED Lights	$0.20	ea	6	$1.20	$0.00	SparkFun Kits
Resistors	$1.60	ea	6	$9.60	$0.00	SparkFun Kits
Hinges	$1.49	pk	2	$2.98	$2.98	Home depot
Acrylic	N/A	N/A	N/A	N/A	$0.00	Makerspace
3D Prints	N/A	N/A	N/A	N/A	$0.00	Makerspace
Velcro	$2.64	pk	2	$5.27	$0.00	Archer's House
Wood	N/A	N/A	N/A	N/A	$0.00	Woodshop and Makerspace
			Totals	$106.02	$47.08	

Appendix G – Project Hours Log

(Archer Huang)

Table 3. Hours log of each team member

	Andrew Enkhsaikhan	Archer Huang	Chloe Flores	Ethan Lazar	Total Work Hours
Milestone 0					
Discuss MS0 Topics	1.5	1.5	1.5	1.5	6
Finalize Team Contract	0.5	0.5	0.5	0.5	2
Totals	2	2	2	2	8
Milestone 1	PM				
Team Charter	0.5	0.5	0.5	0.5	2
Background Research	0	3	5	3	11
Problem Statement	0.5	2.5	2.5	2.5	8
Totals	1	6	8	6	21
Milestone 2		PM			
Market Research	0.5	0.5	0.5	0.5	2
Prototype Design Sketches	2	2	2	2	8
KDTA and Keyvani Meeting	2	2	2	2	8
Cardboard Prototyping	3.5	4.5	4.25	4.5	16.75
Proof of Concept	0	0	0	2.5	2.5
Totals	8	9	8.75	11.5	37.25
Milestone 3				PM	
CAD Design	2	2	2	2	8
Building the Prototype	7.5	12.25	12.25	12.25	44.25
Totals	9.5	14.25	14.25	14.25	52.25
Milestone 4			PM		PM
Build and refine prototype to 100% completion	8	8.5	8.5	10.5	35.5
Feedback planning, visit and reflecting on MCCS visit	2.25	2.25	2.25	1.75	8.5
Make Updates and CAD Design	12	19.25	17	17	65.25
Totals	22.25	30	27.75	29.25	109.25
Milestone 5					

Film a Demo Video	0.5	0.5	0.5	0.5	2
Present at Showcase	1.5	1.5	1.5	1.5	6
Totals	2	2	2	2	8
Milestone 6					
Final Report	3	3	3	3	12
Totals	3	3	3	3	12
TOTAL HOURS	47.75	66.25	65.75	68	