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Solar Panel Educational Exhibit

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Abstract

The problem given by the client was that they need an educational exhibit regarding the science of green energy for middle and high school students in remote areas. The exhibit must provide them with a fun and engaging experience that requires user interaction to explore. The information provided should aid them in their learning experience and should be credible, safe, and intriguing. Size limitations of the exhibit include fitting within 36' inch wide and 28-inch-long dimensions when displayed and fitting within a tote bag when transporting the exhibit. Price limitations include not spending over 100 dollars to make the exhibit and making sure the entire museum did not exceed 1,000 dollars. Given the circumstances, the Fellowship of Wizards worked together to effectively fulfill the client's needs.

The developed solution for this problem was a solar energy-based exhibit that featured a player vs. player true or false question game along with a solar powered race between two cars on a ramp. This provided the users with direct and indirect methods of learning to account for the educational and interactive aspects that were needed. The users actively participated in the true or false competition with one of their peers as well as watching their answers determine how many lights power their motor and car's solar panel. Various SparkFun Inventor's Kit components were used along with game buttons and LED strips. The exhibit was made from saw cut wood, store bought pieces, and 3D printed materials and was painted for detail.

Overall, the developed solution succeeded in some areas of our goals while also not meeting the group's standards in others. The exhibit was aesthetically pleasing and was something the users enjoyed participating in but slightly hindered away from the educational goal due to the game aspect of this exhibit. This technical report goes in depth on the individual processes, details behind the development, and the overall review of the final project.

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JASON LU

1 INTRODUCTION

1.1 PROBLEM STATEMENT

The client requires an educational exhibit on green energy science for middle and high school students in rural areas. The exhibit must be both fun and educational, presenting clear and organized information to allow easy processing by the target audience.

To enhance educational effectiveness, the exhibit should simulate realistic technology use and engage the user. This means capturing the attention of the user throughout usage. Additionally, the exhibit should not be so boring that the user loses interest.

The design must accommodate regular student interaction and meet constraints for easy set up and transportability between schools. This includes fitting within a provided tote bag and taking no more than 15 minutes to set up the exhibit. Once set up, the exhibit must fit within size constraints and not exceed $100 in cost.

1.2 STAKEHOLDERS

The client in question plans to initiate a traveling museum project, with the intended users being middle to high school students. While these students receive a considerable amount of STEM-related education, they may not have regular access to science exhibits due to accessibility constraints.

In addition, it is crucial to note that the showcase at the end of the project will be attended by third-graders, and therefore, this must be factored into the design process. Younger children will have shorter attention spans and be less likely to read dense paragraphs of text. Compared to middle/high school students, third graders would be drawn to more colorful and fun exhibits, rather than exhibits that simply display information.

Besides the primary stakeholders, possible secondary beneficiaries could be teachers and parents of the child. Teachers and parents would rather prioritize an educational takeaway from the exhibit for children rather than just entertainment.

1.3 SOLAR ENERGY

The exhibit presented in this report is focused on the topic of solar energy. Solar energy is a form of green energy that uses power from the sun to generate electricity through the use of solar panels. When a light shines on a solar panel, photovoltaic cells within the solar panel absorb the energy from light rays and turn it into electricity. This is considered a renewable energy source as energy from the sun will not run out for billions of years. While solar power is very viable, the amount of electricity generated is dependent on factors such as weather conditions, orientation or even the angle of the solar panel.

1.4 MATLAB AND SPARKFUN INVENTOR'S KIT

The electronics of the final prototype is coded using MATLAB app designer. MATLAB is a programming language that is widely used for scientific computing, data analysis, and visualization. MATLAB provides software called MATLAB app designer that allows the user to create custom graphical user interfaces (GUI) without needing to write the code itself.

The app designer offers a drag-and-drop interface for creating GUI components such as buttons, sliders, and graphs. This allows the user to quickly create apps quickly and easily.

The Sparkfun Inventor's Kit is an electronics kit designed for students to learn about circuits and electronics. The kit contains various components such as an Arduino Uno red board, sensors, LEDs, wires, resistors, etc. The kit also provides a guidebook that gives instructions for building circuits and programming the red board.

Using the MATLAB app designer to program the Arduino RedBoard Uno from the Sparkfun Inventor's Kit, the team was able to develop an educational interactive game about solar power for children of all ages.

1.5 SCOPE

In this technical report, we will discuss the decision-making process and methodology utilized by our team to reach our ultimate design. The technical report will cover the techniques used to generate ideas, the timeline followed during the design cycle, as well as any alternative designs considered before deciding on the final design.

Additionally, we'll detail the data collection methodology we employed and our analysis of the testing we conducted. Furthermore, this report will encompass the final design in its entirety, including the functions, electronics, CAD drawings, and code, as well as the results of our product testing.

2 BACKGROUND

2.1 RESEARCH

As a group, we began our project by conducting research and gathering information on each type of green energy. Our goal was to gain a thorough understanding of each type so that we could develop a comprehensive and effective museum exhibit.

To aid in our idea generation process, we sought out existing museum exhibits of each green energy. These exhibits served as a valuable reference for us, providing insight into what has worked well in the past and what engages museum visitors.

I focused my research on geothermal power. While this was not the topic chosen for our final design, I still found a helpful exhibit at the Brooklyn Children's Museum [8]. This source was especially beneficial for our project because it targets the same demographic as we do - young children. By studying the exhibit, we could see firsthand what has proven to be effective in engaging and educating children in a museum exhibit.

2.2 UNIVERSAL DESIGN

Universal design in engineering means designing a product that can be used by people of all abilities, ages, and sizes. The goal is to create something that is usable by the widest range of people possible, without the need for special adaptations or retrofitting.

According to the National Disability Authority, there are 7 principles of universal design. They are equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance of error, low physical effort, size and space for approach and use [9].

These principles are especially important as young children have very varying experiences and learning.

3 METHODOLOGY

3.1 RESEARCH AND GOAL SETTING

The team opted to divide the research according to each type of green energy. Each team member is tasked with finding out basic information regarding their assigned green energy, along with existing museum exhibits. This allowed the team to gain a good understanding of each type of green energy and what a possible exhibit could look like.

Additionally, the team came up with a list of group goals that would be eventually used for idea generation and decision analysis. These goals were: Educational, Interactive, Size/Portability, Cost, Realistic, Easy to Build, Collects Data.

3.2 IDEA GENERATION

To generate a wide range of exhibit ideas based on the different types of energy researched, each group member was asked to contribute two ideas using various ideation techniques. These included lateral thinking, which encouraged diverse and creative ideas without any fear of being "wrong".

Jason Lu Ideation technique: **Lateral thinking**

Starting word: Steam

Steam, water, water vapor, vaporizer, humid, humidifier, moist, wet, moisture, hot, weather, sun, sky, solar, plants, nature, earth, ocean, tide, movement, pushing, slide, playground, fun,

Figure 1. Lateral Thinking by Jason Lu

The morphological chart was also used, ensuring that each idea aligned with specific design goals, thereby prioritizing them.

Table 1. Morphological Chart by Ajay Haridasse

Goals	Concepts/Means to Achieve				
Educational	Background Info chart	Step-by-Step process	Simple display		
Interactive	Game	Simulation	Buttons	Switches	Lights
Size/portability	Construct out of cardboard/box	Handle to easily control	Foldable		
Realistic	Power from green energy source	Shows exact process	Simulation	Similar to something in real world	
Easy to build/set up	Minimal Steps	Already set up	Quick reset	No reset needed	

With this approach, any ideas generated were specific to each goal, which ensured a comprehensive and targeted approach. Additionally, analogies were employed to narrow the scope of each idea, leading to specific design ideas.

Figure 3. Analogies by Andrew Hedberg

Andrew Ideation Technique - Analogies

1) This design is similar to a windmill but underwater.
2) Instead of wind rotating the turbine and motor in a windmill, water is rotating the watermill.

By combining these ideation techniques, the team was able to produce a variety of ideas that reflected our values and goals for the exhibit while still being creative and different from one another. The following is a list of ideas generated by the team: Geothermal Exhibit (Jason Lu), Tidal Power Exhibit (Jason Lu), Hydroelectric Car vs.. Solar Energy Car (Ajay Haridasse), Solar Powered Tug-of-War (Ajay Haridasse), Windmill Exhibit (Andrew Hedberg), and Watermill Exhibit (Andrew Hedberg).

Figure 7. Geothermal Exhibit by Jason Lu

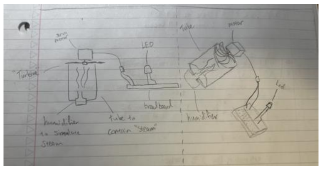


Figure 11. Tidal Power Exhibit by Jason Lu

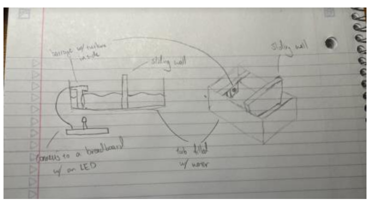


Figure 15. Hydroelectric vs. Solar by Ajay Haridasse

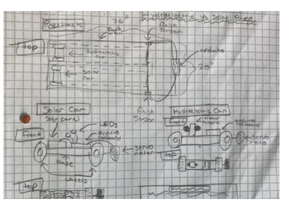


Figure 19. Solar Powered Tug-of-War by Ajay Haridasse

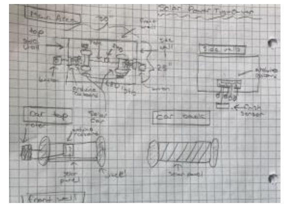


Figure 23. Windmill Exhibit by Andrew Hedberg

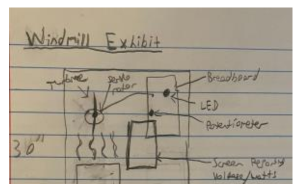
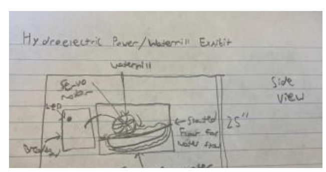


Figure 27. Watermill Exhibit by Andrew Hedberg



3.3 FINAL IDEA SELECTION

After generating a total of 6 different ideas for potential museum exhibits, our team had to select just one singular design to pursue.

To help us make this decision, we first met as a group to rank the relative importance of each goal using a rank order chart.

Table 5. Rank Order Chart

	Educational	Interactive	Size/portability	Realistic	Easy to Build/set up	Collects data	Cost	Total
Educational	-	1	1	1	1	1	1	6
Interactive	0	-	1	1	1	1	1	5
Size/portability	0	0	-	1	1	1	0.5	3.5

The ranking weight was then decided based on the ranking of each goal.

Next, we completed a Kepner-Tregoe Decision Analysis (KTDA) chart as a team, where each design was rated on a scale of 1-10.

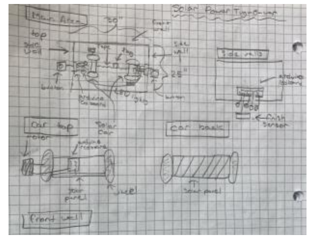
Table 9. KTDA Chart

Group Decision Matrix Ratings for Design Goals														
	Educational		Interactive		Size/portability		Cost		Realistic		Easy to Build		Collects Data		Total
Weights	6.5		5		3.5		3.5		1.5		1.5		1		
Geothermal Exhibit (Jason)	9.50	61.75	5.00	25.00	9.50	33.25	7.75	27.13	7.75	11.63	8.75	13.13	1.50	1.50	173.38
Tidal Exhibit (Jason)	8.75	56.88	8.75	43.75	8.00	28.00	7.00	24.50	7.75	11.63	8.75	13.13	1.50	1.50	179.38
Hydroelectric vs. Solar cars (Ajay)	7.75	50.38	5.50	27.50	7.13	24.94	6.00	21.00	5.75	8.63	5.38	8.06	4.25	4.25	144.75
Solar Tug of War	7.75	50.38	10.00	50.00	8.75	30.63	8.25	28.88	7.25	10.88	8.00	12.00	8.50	8.50	191.25

The score received for each goal was multiplied by the ranking weight previously decided in the rank order chart, and the total score of each design was calculated by adding up the scores received under each goal.

Ultimately, the design with the highest score was selected as the one that we would pursue and construct. This turned out to be the solar powered tug of war designed by Ajay Haridasse.

Figure 22. Solar Powered Tug-of-War by Ajay Haridasse



3.4 IMPLEMENTATION AND IDEATION UPDATES

After selecting a final design, the team met with Professor O'Connell to receive feedback on our proposal. Following the meeting, we made several updates to the design to enhance its feasibility and engagement.

These updates included changing the original design from a "tug-of-war" style game to a solar-powered racing game, removing the button-mashing aspect, and replacing it with a true/false quiz similar to Kahoot. Furthermore, we decided to focus on the appearance of cars and have them appear to be powered by solar energy rather than building an actual car that runs off solar energy.

To ensure that our proposed design was clear, each team member created a CAD drawing of the design in both the transport and display modes.

Figure 31. Display Mode CAD Drawing by Jason Lu

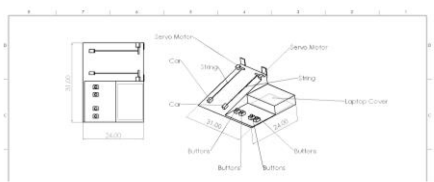
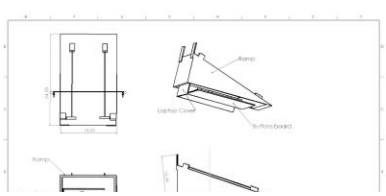


Figure 35. Transport Mode CAD Drawing by Jason Lu



As part of the construction process, we also began to build a bill of materials and gathered the necessary materials to construct a cardboard prototype based on the CAD drawings.

3.5 PROOF OF CONCEPT

To start construction, the team split the work into hardware and software. One person took on the coding aspects while the other two handled the building of the project. The team assumed that if they could code the correct interactions for one player, they would be able to do the same for both. Therefore, the proof of concept was designed to include the code and electronics for only one player, along with just two true/false questions for the user to answer. This would showcase what happens when the user answers the question right or wrong.

To initiate the proof-of-concept demonstration of the game, the user hits the start button on the user interface which starts turning the servo motor at a very slow rate. A question will then pop up on the screen. If the user gets the question right, the servo will start spinning faster and if the user gets the question wrong, the servo will not change speed.

The group determined that certain aspects, such as the solar panel and its corresponding LED, were not included in the proof of concept, as they were either aesthetic or not relevant to user interaction. The team also intended to include more questions in the final design, but only two were necessary in the proof of concept to demonstrate user interaction.

3.6 90% PROTOTYPE

As our team progressed towards the final stages of construction, we began to assemble the physical elements of the prototype. This included constructing the keyboard cover/button board and adding holes for the buttons to be slotted in. A shelf was also installed to hold up the laptop so that it did not cover the bottom of the screen. In addition, the team created 3D printed holders and dowel attachments for the servo and built tracks for the cars to race on. Additionally, the team also intends to include a photoresistor to help determine if a car has finished the race. The photoresistor will be embedded in the track at the finish line and if the light level drops significantly, then that means the car has crossed the finish line. This will cause the servo motor to stop spinning and then reverse direction to act as a reset. Holes were drilled for the photoresistor, and wood pieces were glued to the servo motor for the LEDs to rest on.

Simultaneously, the software aspects of the prototype were being developed. The team completed a second iteration of the code that now allowed for player 2 to answer the question, which had been a crucial missing element in the previous iteration. The code also included functionality for the LED to light up after each player got a question correct. Lastly, the photoresistor was programmed to reset the game after a car crosses the finish line.

3.7 EVALUATION PLAN AND DATA COLLECTION

To best evaluate the success of the exhibit, the team identified several aspects that must be assessed. These include user interaction, educational content, fun/interesting, interactivity, clarity, and aesthetics. To gather feedback from users, the team utilized a survey that rates the exhibit based on the criteria above. Additionally, the team measured the functionality and durability of the exhibit. This involved observing how well the exhibit functioned during the gallery walk and how much wear and tear it experienced after repeated use. By evaluating these aspects, the team could determine the effectiveness of the exhibit in achieving its goals and engaging visitors.

3.8 PROTOTYPE TESTING AND FINAL PROTOTYPE

After receiving valuable feedback from the gallery walk, the team worked on making improvements to the final prototype. These updates included shortening the text and fixing any issues with the code for the game. Additionally, the team addressed the last 10% of the exhibit by completing tasks such as painting and permanently attaching servos and photoresistors. By making these updates, the team aimed to create a more polished and functional exhibit that would better engage and educate users.

3.9 INDIVIDUAL CONTRIBUTIONS

Throughout the project, I played a significant role in researching, ideating, modeling, constructing, coding, and evaluating the exhibit.

In milestone 1, my research focused on geothermal energy and existing exhibits related to this topic.

In milestone 2, I proposed two exhibit ideas - a Tidal Power Exhibit and a Geothermal Power Plant Exhibit. My tidal power exhibit was selected as the backup exhibit as it had scored the second highest in the KTDA chart.

Figure 14. Tidal Power Exhibit by Jason Lu

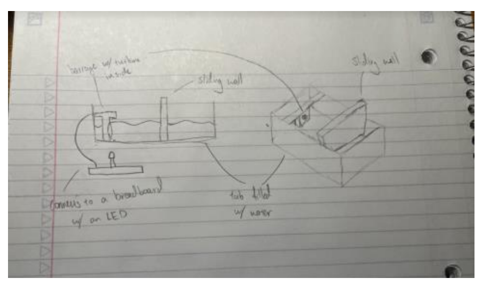
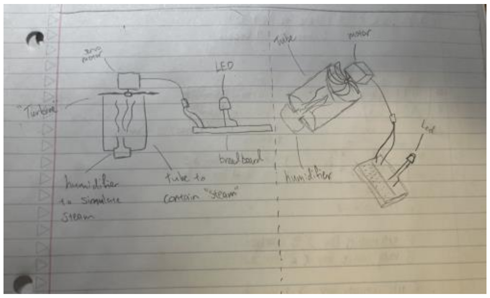


Figure 14. Tidal Power Exhibit by Jason Lu



In milestone 3, I built my CAD model that was used in reference for the cardboard prototype.

Figure 39. Display Mode CAD Drawing by Jason Lu

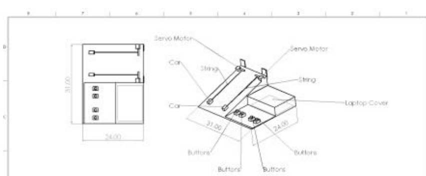
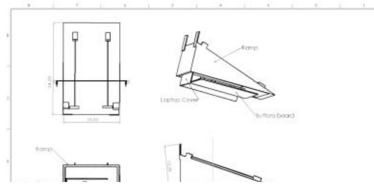


Figure 43. Transport Mode CAD Drawing by Jason Lu



I also collaborated with Ajay Haridasse in constructing the cardboard prototype.

In milestone 4, as project manager, I facilitated the building process and coded the proof of concept, as well as wired the electronics.

In milestone 5, I helped fix the code for the interactive game, completed the wiring for the final prototype, and assisted in its construction.

Finally, in milestone 6, I was responsible for setting up and any troubleshooting during the showcase. After the showcase, I filmed and edited the demo video.

AJAY HARIDASSE

4 INTRODUCTION

4.1 PROBLEM STATEMENT

The client needs an educational exhibit on the science of green energy with the target user being middle and high school students that do not have easy access to museums. The purpose is to teach and engage the user in an interactive way, so the exhibit must balance the educational and fun aspects as well as making sure the information presented is effective and brief.

The user needs to be properly educated on the science of green energy, meaning the exhibit must accurately depict or present how green energy works and needs to be realistic to its use in the real world. The information provided must also be presented in a clear and concise manner to make sure the user is able to clearly understand the purpose and content of the exhibit. The exhibit also must have a simple method of interaction, so the focus is primarily on education rather than functioning the exhibit.

The makeup of the exhibit must be small enough and easy to transport along with not requiring a difficult assembly and disassembly. The exhibit will be traveling from school to school, so it must fit within dimensions of 36 inches wide and 28 inches in length while in display mode and within a tote bag during transport mode. The exhibit must efficiently use the money spent to produce a quality product, as the spending limit for the exhibit and entire museum is 100 and 1,000 dollars respectively.

4.2 STAKEHOLDERS

The intended stakeholders of this project include the users, the middle or high school students that will be actively using the exhibit, as well as the clients, the institutions that are setting up these mobile exhibits for the students to experience within their own school. At the first-year engineering expo where the exhibit is presented, third and fourth graders will be using the exhibit meaning this will need to be accounted for in the design process. Along with this, potential secondary beneficiaries include the teachers of the students.

Considering the exhibit is intended for middle and high school students but will also be used by third and fourth graders, this will need to be accounted for. Due to their differences in education levels and attention spans, it must be suitable for both groups. To make sure all audiences will be able to successfully use and learn from the exhibit, information will need to be provided in simple and organized text. The complexity of the interaction must be catered to the younger audience as well as the aesthetics to ensure all target users can properly engage with the exhibit.

The teachers of the students are considered secondary beneficiaries considering they are not directly involved with the exhibit unlike the students and schools. Despite this, the teachers will still benefit from the educational effectiveness of the exhibit based on how the students learn from it. Due to them only benefiting from one of the many different aspects of the project, they are not as impacted as the primary stakeholders.

4.3 SOLAR ENERGY AND SPARKFUN INVENTOR'S KIT

This exhibit focuses on the topic of solar energy while also using the SparkFun Inventor's Kit to make the learning experience for the user interactive.

Solar energy is a type of renewable energy that is converted into electricity from solar power. Solar energy can be harvested using solar panels that contain photovoltaic cells (PV Cells) that absorb sun rays to generate electricity. Any light can hit these solar panels to produce electricity, and since the sun is a light source that will never go away, solar energy will never run out [10]. In addition, because solar panels produce energy when light shines on the PV cells, the amount of energy produced is dependent on the angle and amount of light that hits them [11].

The SparkFun Inventor's Kit (SIK) consists of simple electronics such as sensors, wires, and other components that can be used with the Arduino coding. A wide variety of programs and games can be constructed and coded that read user inputs and display or write to different electronic components. Using the SIK allows simple setup of programs while also allowing simple user interaction through physical buttons and motors or a graphical user interface with MATLAB. Combining the two, education through the use of the kit can be accomplished in a way that uses user interaction to work its way through the program [12].

4.4 SCOPE

This document serves as the final technical report of the project, covering all aspects of the engineering design process. It discusses the initial problem along with the background research completed to understand and tackle the problem, the idea generation and group decision making process, the planning and prototyping stages, and the finalization and reflecting portions of the project. The final project and its performance are discussed thoroughly along with in depth analysis of the project as a whole and its development over the course of the past 10 weeks.

5 BACKGROUND

5.1 RESEARCH

The group's first task in terms of research started with looking into hydroelectric energy, tidal energy, geothermal energy, solar energy, wind energy, and biomass energy. From there, the group also investigated existing exhibits for each type of museum exhibit. Along with looking into this, research was done on conducting a successful museum exhibit to aid the idea generation process when it came time to develop ideas for actual exhibits. Doing this helped the group begin to deal with the problem of needing to properly educate the user on the topic of green energy through a museum exhibit, as well as helping the group determine the best way to educate and present it to them.

Due to the selected exhibit topic being focused on solar energy, the research pertaining to wind energy, biomass energy, geothermal energy, hydroelectric, and tidal energy were irrelevant. However, the research regarding existing exhibits, tips about successful exhibits, and solar energy helped in the next step of the project. Looking into existing green energy museum exhibits despite the topic not matching the groups was very helpful considering it helped us in every other area of the project besides the content presented.

Figure 14. Tidal Power Exhibit by Jason Lu

One exhibit that was looked at was the Museum of Science's Wind Turbine Lab. How the Wind Turbine Lab exhibit is set up is shown in figure [13].

This exhibit featured results from a three-year long lab that took place on the roof of the museum, as well as presenting basic information on wind energy and how it works. This exhibit provided a model example of what a successful educational exhibit looks like considering the information was well organized, it connected the topic through a realistic study, and it was an aesthetically pleasing overall exhibit [1].

Figure 47. Solar on the Line Exhibit

Another exhibit that was looked at was the Solar on the Line exhibit featured in the Smithsonian National Museum of American History. This is in Washington D.C. How the Solar on the Line exhibit is set up is shown in figure [14].

This exhibit goes in detail on the basics of solar energy as well as the history and benefits that it brings as a green energy source. This exhibit's topic ended up being the same topic as the group's selected topic, so it was an even more helpful model exhibit that provided help on what should be included in a solar energy-based exhibit. It was also aesthetically pleasing as it featured bright colors, different pictures and sections, and wasn't just bulked up into one area [14].

Additionally, researching successful and unsuccessful traits of museum exhibits was beneficial considering the group has not constructed a museum exhibit in the past. Making sure the exhibit incorporates some of the tips listed within the ColorCraft article, including using graphic design to create flow, focus, and interest, embracing technology within the exhibit, and making sure the exhibit has a linear flow, are all things that would benefit the effectiveness of the exhibit as a whole [2].

The research done on the selected exhibit topic, solar energy, provided the group with what exactly we were going to include in our exhibit. Considering the intended users, the group decided that only basic information on the topic would be included.

Solar energy is a renewable source that turns sunlight into electricity using solar panels that contain photovoltaic cells (PV Cells). These panels generate electricity when exposed to any light source, making solar energy an endless supply. Solar energy does not pollute and put greenhouse gasses in the air unlike fossil fuels making it a clean alternative. The amount of energy produced is determined by the angle and intensity of the sunlight. Along with this, solar energy is proven to be one of the better green energy sources as it does not require much money or maintenance to produce solar energy long term. Despite its benefits, it does require a good amount of money and land to implement large scale solar panel farms. However, if the space and money is there, solar energy is a clean and renewable energy that is much safer for the environment than others [10][11].

After combining everyone's research together, this allowed the group to move forward with the project with a general understanding of potential exhibit topics, ways to display this information effectively and cleanly, and what exactly is going to be displayed in the exhibit.

5.2 ETHICS

Throughout the entirety of the project, the group ensured that ethical considerations were made in every aspect. Along with creating group values that were used in order to produce exhibit ideas with a value sensitive approach, the group also made sure that as engineers, ethical considerations were made with the information that was presented as well as the safety of the exhibit.

Four goals were determined that matched the group's ethics to be reflected and demonstrated in the final design. These four goals were creativity, personal development, competition, and gaining wisdom. When generating the initial ideas for the exhibit as well as updating and finalizing the selected exhibit, the group ensured these four goals were incorporated.

In terms of ethical standards, considering the intent of the exhibit was to educate the user, the group focused on implementing a design that depicted and described the topic of green energy in a realistic way. The group also wanted to ensure that however the design was implemented, the final was constructed in a clean and organized way. Safety and attention to detail are very important not only for the group but for the client and user as well. Accounting for this gives the exhibit credibility in a physical and educational way, as showing maximum professionalism and care with the detailing of the project will allow all stakeholders to benefit.

5.3 UNIVERSAL DESIGN

As defined by the University of Washington's DO-IT program, universal design is "the process of creating products that are accessible to people with a wide range of abilities, disabilities, and other characteristics" [3]. In terms of the project, this would mean creating an exhibit that all users would be able to participate in. This means the group needs to account for intellectual or physical limitations. For all users to effectively learn, the information provided must include enough context so that anyone of any background can have a positive experience with the exhibit. Although the users of this exhibit range from third and fourth graders to middle and high school students, the physical limitations of the users are unknown. For the design to be universal, making sure the interactive elements of the exhibit are simple and safe to use was necessary.

6 METHODOLOGY

6.1 PROBLEM DEFINITION

For the first step in the Wizard's design process, the first week of the project (Appendix I) consisted of overviewing the specifications of the project and the exact needs of the client. The client needs an educational exhibit pertaining to the topic of green energy for middle and high school students.

The exhibit is for students in remote areas that do not have access to museums, so it needs to be able to travel from school to school. This means it should not require a difficult set up and breakdown, as it must only require 15 minutes for 2 people to accomplish this. The exhibit also needs to fit size requirements of 36 inches wide and 28 inches long while in display mode, and it must fit into a tote bag while in transport mode. Along with fitting these requirements, the exhibit must be durable to withstand the travel from school to school.

The exhibit's educational experience must be interactive as it must feature at least two interactive elements. Component requirements include at least two unique SparkFun Inventor's Kit components and at least one 3D printed, CNC milled, or laser cut part. Along with this, the exhibit must be presented in an organized and professional manner in order to maximize and produce the highest quality experience for the intended user. Overall, the exhibit's cost must not exceed 100 dollars and the overall museum must not exceed 1000 dollars. Using these needs and limitations, the group was then able to know exactly what needs to be accounted for and researched to move forward.

6.2 RESEARCH AND DECISION-MAKING PROCESS

In order to appropriately approach the problem, the group also spent the first week splitting up and individually researching the different forms of green energy, existing exhibits, and methods of conducting museum exhibits. This allowed us to view all potential exhibit ideas and to give us ideas on how the exhibit should be constructed and presented. After coming together, the group initially narrowed down our potential topics by eliminating biomass energy and tidal energy considering finding existing exhibits about these forms of energy were difficult. However, despite concluding that these were considered too difficult to model in a way that would be physically made, ideas of the exhibit that were virtual simulations would still be accepted.

The following week (Appendix I), the group split off once again to create individual design sketches of exhibit ideas. Using a variety of creativity processes, including a morphological chart, lateral thinking, and analogical thinking, each member composed two separate exhibit ideas that they believed would fit both our ethics and group values.

Following this, the group then developed a list of design goals to rate and select a final design, with the design goals being education, interactivity, size and portability, cost, how realistic it is, ease of build, and ability to collect data. On a scale of 1-10, each group member rated every concept design based on all the design goals, with each rating being averaged out among the four group members.

Table 8. Rank Order Chart

	Educational	Interactive	Size/portability	Realistic	Easy to Build/set up	Collects data	Cost	Total
Educational	-	1	1	1	1	1	1	6
Interactive	0	-	1	1	1	1	1	5
Size/portability	0	0	-	1	1	1	0.5	3.5
Realistic	0	0	0	-	0.5	1	0	1.5
Easy to	0	0	0	0.5	-	1	0	1.5

To accurately score each design, weight values were created for each of the goals using a rank order chart so the group could properly select the best design. The full rank order chart is shown in table [2].

Education was the highest priority which resulted in it being weighted at 6.5 points, with interactivity having a weight of 5 points, size / portability and cost with 3.5, how realistic it is and ease of build with 1.5, and ability to collect data with 1.

Table 8. Rank Order Chart

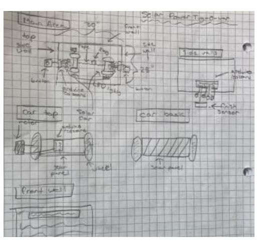
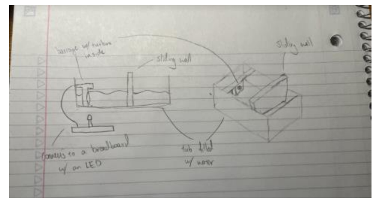


Figure 51. Tidal Power Exhibit by Jason Lu



Using the average ratings of the four design grades and applying the weightings to each design goal rating in a Kepner-Tregoe Decision Analysis chart (Appendix B), the selected design that the group planned forward with was the Solar-Powered Tug-of-War, with the Tidal Simulation Exhibit being our backup plan, as they scored 191.25 points and 179.38 points respectively. Concept sketches of the Solar-Powered Tug-of-War exhibit and the Tidal Simulation exhibit are shown in figure [6] and figure [15].

These selections were made considering their high scores in the educational and interactivity ratings, and considering these factors were the main areas of focus, they were clear selections. As a group, it was also agreed that it was in our best interest to select the Tidal Simulation as a backup considering this was a much safer and more reliable option for an exhibit, since at the time the group agreed that the components of the Solar-Powered Tug-Of-War game would be too complex.

6.3 INITIAL PROTOTYPING AND PLANNING

Following the selection of our primary and backup plans for exhibits, the next week of the project (Appendix I) started off with the group ultimately deciding to modify the Solar-Powered Tug of War exhibit considering some of the aspects were deemed too complex and was taking away from the purpose of the game. Using Professor O'Connell's feedback as well as discussing more feasible features, the group changed a couple of the primary elements. This allowed the group to continue the general idea but in a more convenient way.

This original idea was a user vs. user button mashing game that resulted in more LEDs lighting up and powering one solar powered car to tug another car across a finish line. Despite the group liking this idea, too many issues arose when trying to figure out how to construct it. The group believed button mashing took away from the educational aspect, figuring out how to power the solar panel cars was too difficult, and resetting the game would be too difficult, so it was changed.

The modified game consists of two cars with string attached to each being winded up a ramp by a motor while two users compete in a true or false question game to get their car up the ramp faster. Along with this, as more true or false questions are answered correctly, LEDs in front of a solar panel will light up to give the users the impression that when more lights are in front of the solar panel, the motors are powered more. A more detailed look at the way the users interact with the exhibit is shown in Appendix G.

Figure 55. Display Mode CAD Drawing by Jason Lu

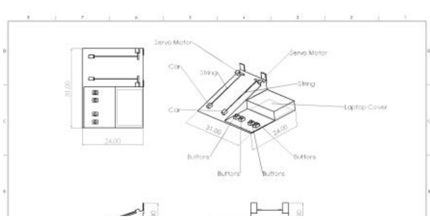


Figure 59. Transport Mode CAD Drawing by Jason Lu

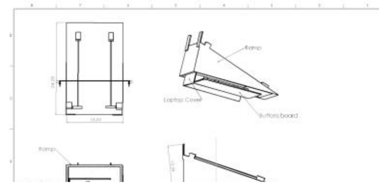


Figure 63. Cardboard Prototype of Solar Energy Race Exhibit

After finalizing the selected exhibit concept, the rest of the week consisted of developing SOLIDWORKS drawings to depict the project. It was also spent creating a cardboard prototype to physically display the makeup of what the exhibit would look like and how it would be dimensioned. The SOLIDWORKS drawings that the group decided to model the cardboard prototype after are shown in figures [16] and [17], and the cardboard prototype is shown in figure [18]. A more detailed look of the cardboard prototype is shown in Appendix H. The exhibit features three main pieces, the primary piece being the ramp with the cars with strings, motors, LEDs, and fake solar panels. The secondary pieces, which were later combined, are the button board with each player's true or false buttons and the keyboard cover with the informational text surface for educational purposes.

6.4 PROTOTYPE UPDATING AND PROOF OF CONCEPT

The next week of the project (Appendix I) consisted of completing 60% of the final exhibit, developing a proof of concept of the exhibit, and developing a method of evaluation for the gallery walk taking place in the following week. The group began by gathering and developing the list for the necessary materials needed to create the final exhibit. The final and full bill of materials is shown in Appendix K.

Figure 67. Upside-Down Combined Keyboard Cover and Button Board During Construction

The original cardboard prototype was used as a basis for the locations and dimensions but was replaced with wood for the base of the exhibit. To further hide wiring and simplify the building of the exhibit, the button board and keyboard cover were combined. The combined keyboard cover and button board during its construction phase is shown in figure [19]. Along with the base, the game buttons that would be used in the final design were implemented, but not put directly into the button board as this was not needed to describe the concept of the game. The buttons were just placed on the surface of the keyboard cover with the wires hanging freely for this stage.

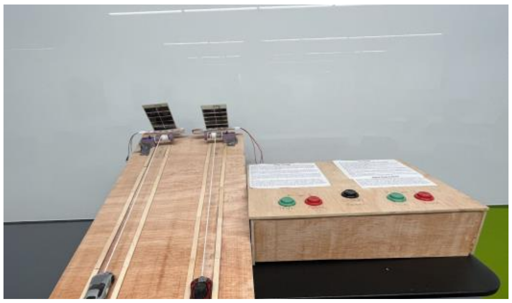
For the proof of concept, the group showed how one of two users will interact with the exhibit using the MATLAB application, one player's motor and car, and their corresponding true or false buttons. With two prompted true or false questions on the MATLAB interface, this demonstrated the motor speeding up when the user answers a question correctly and the motor staying at the same speed when answering a question incorrectly. It also shows that when the game is reset, the car winds back down to the bottom of the ramp for the next run of the game. Key features including all the other player's parts, the photoresistors used for stopping the game that will be covered when the car reaches the top of the ramp, and the LEDs with fake solar panels were not implemented at this point and were addressed when completing up to 90% of the exhibit.

To prepare for the gallery walk taking place upon completion of 90% of the final exhibit, the group developed an evaluation plan regarding the many different aspects of the project. Our evaluation plan consisted of our own observation of the exhibit to watch for errors and durability issues as well as a survey that the users filled out regarding each aspect of the exhibit. This asks the users to rate different aspects based on its functionality and effectiveness as well as prompting them with questions that help us improve on the exhibit. The chart for the evaluation plan along with the survey used that details the entire evaluation can be found in Appendix I.

6.5 GALLER WALK AND FEEDBACK

The following week of the project consisted of building the exhibit up to 90% complete and following through with the previously formed evaluation plan (Appendix I) from the previous week. How the work was distributed is highlighted in Appendix J

Figure 71. 90% Complete Solar Energy Exhibit



In order to complete 90% of the exhibit, everything aside from the aesthetics of the project was taken care of. The 90% complete prototype is shown in figure [20]. Numerous features were implemented and attached to the ramp including the non-functioning solar panels, holders for the servo motors, the servo motors themselves, 3D printed dowels for the strings of the cars to be attached to the motor, informational text on the keyboard cover surface, as well as the LED strip placed in front of the ramp. Holes at the top each side of the ramp were implemented for the photoresistors to go through along with holes in the button board for the buttons to go through for a clean appearance. New additions to the exhibit that were previously not expected include a shelf at the opening of the keyboard cover where the computer will rest to also ensure the screen is not covered due to being too low and additional button and buttonhole on the button board as a start button. Photos of the different components of 90% completed exhibit and at different angles are shown in Appendix H.

Aside from the physical aspects of the exhibit, the software for the game was also completed, as the code added components for player 2, more questions for the users to go through, reset when the cars cover the ramps photoresistors, and the newly added start button. The completed and commented code are shown in Appendix E.

Despite confidence in the completion of the exhibit, the code was not fully ready resulting in the game not properly functioning throughout the gallery walk. When players spammed the buttons, the game crashed, and at times when the car ran over the photoresistor, the game did not stop. Even though the game did not function as expected feedback on all the other aspects of the exhibit was given. Full feedback from the gallery walk is shown in Appendix I. Overall, the main criticisms received from the gallery walk include putting too much informational text, the questions of the game being too long, and the wiring and organization of the exhibit being poor. The aesthetics, the feedback provided, and fixing the code were all things addressed in order to fully complete the exhibit.

6.6 FINAL TESTING AND EVALUATION

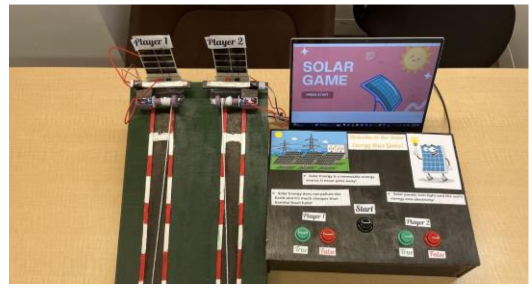
Completion of the exhibit consisted of taking care of the aesthetics of the exhibit, organizing the wires for a cleaner look, shortening the informational text, and fixing the code. Over the course of the next week, the group divided by handling the code and the aesthetics separately (Appendix J).

To fix the errors of the game from the gallery walk, the code was rewritten in order to accommodate for players repeatedly clicking the true or false buttons. This allowed the game to run as planned. The code was also changed to ensure the game stopped exactly when the first car ran over their side's photoresistor, so this was no longer an issue as well.

Figure 75. Completed Exhibit

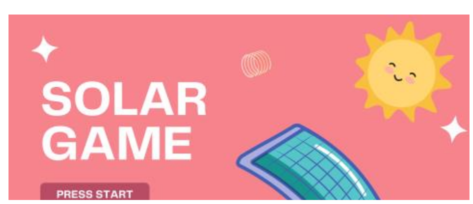
The first step in completing the aesthetics of the exhibit consisted of painting and how all pieces were connected. The group used paint to cover the color of the wood and components that were originally taped were glued on after painting was completed. The complete exhibit is shown in figure [21]. The keyboard cover / button board was painted in black to provide a nice contrast between the educational text that would be on white paper. The ramp with the cars and track was painted to model a racetrack. The track sides were painted in alternating red and white, the track itself was painted black, and everything else around it was painted green.

Figure 79. Keyboard Cover/Button Board Surface



To address the feedback from the gallery walk, not only was the instructional and informational text shortened, but the instructions were moved to the MATLAB user interface. This allowed the keyboard cover / button board surface to be more organized and have more space. The keyboard cover / button board surface is shown in figure [22]. With the space, three solar energy informational bits, two solar energy related pictures, and the title of the game was printed and glued onto this surface. One picture features a typical solar panel farm with the sun shining on them while the other features a cartoon solar panel with arms and legs to appeal to the kids. Labels for every button as well as each player's buttons were also printed and glued on to provide more guidance.

Figure 83. Solar Energy MATLAB Start Screen



For the MATLAB user interface, the graphics were also changed to be more visually appealing. Multiple slides were created with one for the start screen, one for the instructions, one for each question, and then one to display the winner. The start screen for the MATLAB interface is shown in figure []. The rest of the slides are shown in Appendix H. The instructions to play the game were originally supposed to be on the surface of the keyboard cover / button board but were moved to the user interface so the users would not be able to miss it.

Additionally, the wires that were originally scattered all behind were moved so that they were all under the ramp. This made sure all wires were covered under the exhibit, making the presentation look much cleaner. After finalizing the exhibit, it was ready for the expo. Multiple photos of the final exhibit at different angles and photos of individual components are shown in Appendix H.

For the project expo, the group collected data on how much time each set of users played the game, the question the game ended on, as well as comments and feedback about our exhibit. How long each game lasted and when it ended depends on how many questions are answered correctly. Seeing these statistics allowed us to see how much the users learned during their experience. Comments on the exhibit ranged from the aesthetics to the user's general opinion on the game, so this also helped in evaluating the final project. This allowed the group to see where goals were effectively met and where they were not.

6.7 INDIVIDUAL CONTRIBUTIONS

For this project, I was a key contributor in every milestone as I provided an insightful perspective to the group that allowed us to develop over the course of the second half of the semester. In the early stages of the project, specifically in milestones 1 and 2, I provided the group with background research regarding solar and biomass energy along with existing exhibits on these topics. This information allowed us to properly narrow down our topics and move forward with the project, leading into the next step, idea generation.

Figure 22. Solar Powered Tug-of-War by Ajay Haridasse

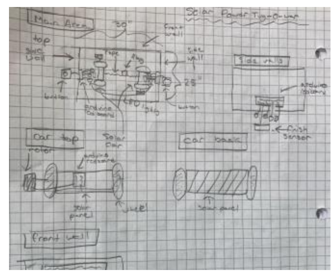
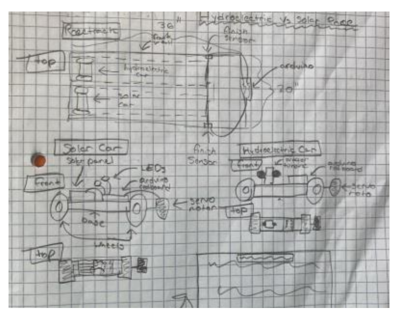


Figure 18. Hydroelectric vs. Solar by Ajay Haridasse



During this stage, I proposed the hydroelectric and solar powered car exhibit as well as the exhibit that we ended up selecting, the solar powered tug of war exhibit. Pictures of my concept sketches are shown in figures 5 and 6.

Figure 87. Display Mode CAD Drawing by Ajay Haridasse

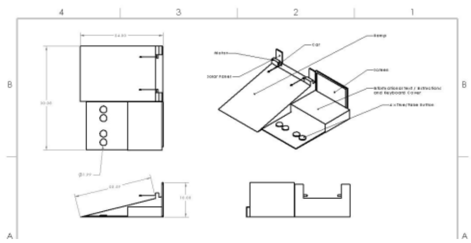


Figure 91. Transport Mode CAD Drawing by Ajay Haridasse

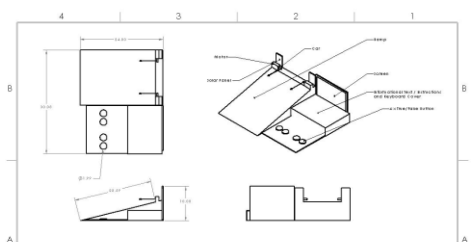


Figure 95. Cardboard Prototype of Solar Energy Race Exhibit

The third milestone, where I was the project manager, consisted of distributing work as well generating a baseline prototype. The initial prototype was made by first creating SOLIDWORKS sketches so we could then visualize how our exhibit would be dimensioned and how it would be oriented. I contributed by developing my own SOLIDWORKS sketches in display and transport mode. My SOLIDWORKS drawings are shown in figures 24 and 25. Jason and I worked together to create a prototype based on what the group agreed to be the best SOLIDWORKS design. A picture of our cardboard prototype is shown in figure 18. As project manager I divided the work among the group members based on everyone's strengths. This allowed us to effectively get through the milestone and make our way onto the next milestone of the project.

The fourth milestone was when as a group we built our 60% prototype, developed our proof of concept, and created an evaluation plan for the gallery wall. Individually, I mainly focused on developing the evaluation plan, so we knew exactly what needed to be fixed or enhanced for completion of the project. Going into the final milestone, this allowed us to easily add the finishing touches, account for the things we did poorly in the gallery walk, and to limit errors throughout the expo.

Overall, I took on the responsibility of summarizing and writing the bulk of our weekly work into the memorandum as I feel like writing is one of my strengths. This allowed other group members to focus more on the project itself, allowing all aspects of the project to be fully tended to.

ANDREW HEDBERG

7 INTRODUCTION

7.1 PROBLEM STATEMENT

The client needs an educational and interactive exhibit on the science of green energy for middle and high school students. The exhibit will be in place of a museum which they don't have access to. The exhibit must educate the users while maintaining a balance of education, fun, and interactivity. The amount of educational information and content presented to the user needs to be appropriate. Specifically, the educational information provided must be organized and clear to ensure the user is able to understand it in a short amount of time. To make sure the user gets the most out of this learning experience, the exhibit must accurately model or include how green energy works and should be realistic to how it is used in the real world. The way the user learns from this exhibit is also a point of focus, as the exhibit needs to make sure the user is engaged and learns based on the process of exploration and interaction with it. This process of exploration must not be too complex so the focus will still be learning about the science of green energy rather than figuring out how to function the exhibit.

There are specific requirements that need to be met, specifically the exhibit must be small and cannot exceed 28 inches long and 36 inches wide. The exhibit must be easy to set up, allowing for the exhibit to be easily transported from school to school. Additionally, the exhibit must have the ability to be assembled and disassembled without extreme effort and should take no more than 15 minutes to do so. The client has set a limit of $100.00 for the prototype and $1,000.00 for the completed exhibit. Making sure the users learn from the exhibit is important, but also making sure money is efficiently spent so the total costs do not exceed 100 dollars. The quality and effectiveness of the overall project will ensure both the client and group benefit.

7.2 STAKEHOLDERS

The primary stakeholder is the client who is tasking the design team with creating this portable, interactive, and educational exhibit. The users of the exhibit, for whom the project is designed to accommodate, include high school, and middle school students who do not have access to museums. Additionally, there are secondary stakeholders such as the 3rd and 4th grade students, their teachers, and other college students who will be utilizing the exhibit during the First Year Engineering Exposition. For these secondary stakeholders, specifically the 3rd and 4th grade students, their attention span, and ways they learn and engage with the exhibit differ greatly from middle school and high school students therefore considering ways to make the exhibit cater to them is necessary. We did this by including fun graphics and pictures and small amounts of text to retain their attention and keep them engaged and interested in our exhibit, which can inspire them to learn and interact effectively with our exhibit.

7.3 SOLAR ENERGY

The topic of our exhibit is solar energy. Solar energy is a renewable form of energy that is harnessed by using solar panels also known as photovoltaic cells, to convert sunlight into electricity. Solar energy is renewable because the energy emitted by our sun will last a long time. The biggest downsides to solar panels are that they can be expensive to initially install, they are very location dependent because the panels need to be facing the sunlight to generate electricity, and weather conditions and time of day affect overall performance of solar panels as well. However, despite this right now approximately 4% of global electricity generation is conducted by solar energy [5]. Solar energy can become one of if not the possible solutions to reducing reliance on fossil fuels and non-renewable energy to help the environment and make a sustainable way to generate electricity.

7.4 COMPUTER AIDED DESIGN (CAD) AND SPARKFUN INVENTOR'S KIT (SIK)

The utilization of the CAD software SolidWorks assisted greatly in the planning and construction of our project. SolidWorks helped us in determining where various elements of our project would be located and how they would be positioned. SolidWorks also allowed us to conduct rapid prototyping specifically by 3D printing the servo motor holders and dowels twice to achieve our desired design.

The Sparkfun Inventor's Kit (SIK) contains a variety of electronic components like sensors, LEDs, resistors, a solderless breadboard, and an Arduino Uno as well as a guidebook with instructions for creating different projects with the circuits and code included. The Arduino programming language can be used to code to specific electronic components which can be used in a game or exhibit. Specifically, the integration of buttons, servo motors, and a GUI through MATLAB are achievable with the SIK. An exhibit can be created where user interaction is required, and educational components can simply be added giving the exhibit an educational experience while simultaneously being interactive and fun.

7.5 SCOPE

This technical report documents and explains in detail all parts of the engineering design process undergone throughout the course of this 10-week project. The engineering design process began with defining the problem and the initial problem statement. After that the research and gathering of information allowed for the development of alternative solutions through idea generation and led to choosing the best solution. Rapid prototyping and planning followed to create proof of concept. After a proof of concept, a functional prototype was fabricated. The prototype was finalized by securing the design and adding aesthetics. Finally, the testing and evaluating of the final prototype was conducted. All these steps led to the final prototype functioning as intended and containing all physical components thereby serving as an educational exhibit meeting requirements set by the client.

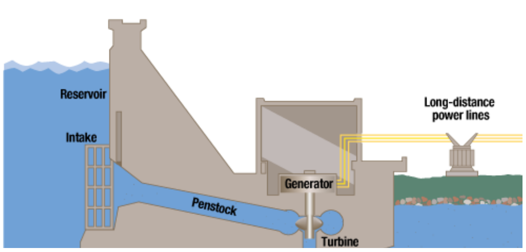
8 BACKGROUND

8.1 RESEARCH

The research process involved the splitting up of research to each group member. We split up research based on different types of green energy (solar, hydroelectric, wind, tidal, geothermal, and biomass). The specific green energy research I conducted was on hydroelectric and tidal power.

Hydroelectric power is one of the oldest and largest sources of green energy in the United States. Hydroelectric power makes up a staggering 31.5% of total green energy generation this equates to about 6.3% of total generation of electricity in the United States. Hydroelectric power facilities come in all different shapes and sizes some facilities are as big as the hoover dam, but others can be small. All hydroelectric power facilities operate in a similar manner by taking advantage of water flows and elevation changes using a dam like structure. Hydroelectric power is one of the most affordable green energies. States in the United States that generate most of their electricity through the use of hydroelectric power are found to have lower energy bills in comparison to other states [#].

Figure 99. Components in Most Hydroelectric Power Facilities



Water is usually held in a man-made reservoir and is released through the dam which spins the internal turbines that are connected to a generator which then produces the electricity, and the water is then discharged out the other side of the dam to a lower elevation [#]. This research on hydroelectric power was helpful for our project because it helped us understand that hydroelectric power is a very versatile green energy because it is affordable, feasible, easy to use, and is relatively simple. This research was also helpful for our project because it detailed the step-by-step process of hydroelectric power and the different components involved in hydroelectric power facilities.

Tidal energy uses a wind turbine under water but instead of using wind to rotate the blades it uses the tide. Inside of a tidal turbine there is usually a gearbox which turns when the tide rotates the blades which then also turns a generator which creates electricity. Like other green energies the location is a crucial aspect of the implementation of tidal turbines the determination of where they should be planted is crucial to their success because some locations yield higher tides than other locations and have different geographic features that influence increased use of tidal turbines like higher or lower elevation changes and the type of ecosystems around the location. This research was very helpful to our group because it helped us understand that tidal energy is similar to a wind turbine but underwater, the implementation process which includes the strategic placement and location of tidal turbines which plays an important role in their success [#].

In addition to researching these two types of renewable energy I also researched examples of museum exhibits and information to assist in the process of generating ideas for creating our exhibit.

Although our selected exhibit's green energy was not hydroelectric or tidal and instead solar, the research I conducted pertaining to examples of museums served to be helpful. Specifically, a source I obtained was from the Museum of Hydroelectric Energy located in a small town in Northern Italy called Cedegolo. This source explains the history behind the hydroelectric energy plant of Cedegolo. Today there is a Museum in Cedegolo which has multiple exhibits that highlight how hydroelectric power works and the fascinating industrial components involved in hydroelectric power facilities. This source is important to our project and researching the important components of exhibits because in this museum the history behind the hydroelectric plant of Cedegolo and how hydroelectric power works are being displayed. This museum uses multiple screens, interactive elements and exhibits, visual aids, and cartoons to help people understand hydroelectric power and its history in Cedegolo [6].

Figure 103. Exhibit in the Museum in Cedegolo, Italy

As shown in Figure [28] the users are gathered around an exhibit and are looking at screens that contain information and graphics showing the users the different components and processes involved with hydroelectric power along with the actual turbine being in front of them. This provides the users a more visual and realistic educational experience which also leads them to being more engaged in the exhibit.

Tidal energy was used around 1630 in Boston's North Cove. The West End Museum explores the history behind tidal energy and the application of it in the Boston area. This research is relevant to our project because it demonstrated to us that tidal energy just like many of the other green energies have been around for a long time and the continued use and creation of these systems need to be continued in order to advance people's quality of life, solve the ongoing crisis of over-exploitation of non-renewable resources, and the overall access of electricity for all people [#].

Figure 107. Exhibit in West End Museum in Boston, Massachusetts

Shown in Figure [29] is another exhibit, this one is from the West End Museum which in it contains many different real artifacts, pictures, and information that help the viewers of the exhibit visualize and learn the history of Boston and how tidal energy was used in Boston during the 1600s. As shown in Figures [28] and [29] the exhibits in both the museum in Cedegolo, Italy and Boston, Massachusetts use visual and realistic representations of material to get users/ viewers of the exhibits to be engaged and as a result learn from their experience. This is important to our project because many of our goals revolve around engaging the users and providing an educational, interactive, and realistic experience using our exhibit.

8.2 ETHICS

Throughout the design process we made sure that our practices and project met goals that we created that served as our ethical guidelines. The goals that we set up reflected what we wanted our project to achieve, which were making sure our exhibit was safe, educational, interactive, portable, cost effective, realistic, and easy to build. We incorporated a value sensitive approach into our design as we worked through the design process starting with the utmost important factor, the safety of the users. Throughout the construction of our project, we made sure our project had no areas where users could injure themselves this was fairly simple and to do this we made our exhibit small and users were required only to push buttons on a stable wooden box in response to the prompts on the MATLAB application.

Making our exhibit educational all while also being interactive was another point of focus which resulted in us creating our true or false game on solar energy. The users would have to answer questions relating to solar energy using true or false buttons to win the game. Due to our exhibit being a two-player game the users were competing against each other, and this would perhaps further motivate the users to interact with our exhibit and learn from their experience with the end goal being to win.

Cost effectiveness and ease of building were the next values that needed to be considered and these were relatively easy to implement into our design. We acquired most of our components for our design from FYELIC, our project manager Professor O'Connell, and our sparkfun inventor's kits. For components/ materials we did need to purchase we used inexpensive wood, acrylic paint, hot wheels cars, and paint brushes all totaling up to $31.40. Our design was easy to build because many of the components were separate and the construction process mainly consisted of creating a wood ramp and box and implementing small features onto the ramp and box.

8.3 UNIVERSAL DESIGN

Universal Design is one in which the design is accessible and usable by many different users with different backgrounds. This type of design eliminates the need for adaptation or a specialized design. The goal of universal design is to create environments and products that are inclusive and welcoming to everyone, regardless of their abilities or limitations. The Chief Information Officers Council denotes Universal Design as being "The design and composition of an environment so that it can be accessed, understood and used to the greatest extent possible by all people regardless of their age, size, ability, or disability" [7].

Understanding and applying a universal design to our prototype would include making sure the target audiences and others can easily understand and use the exhibit, it is safe to use, and not physically demanding or requiring background knowledge on solar energy or the exhibit itself.

9 METHODOLOGY

9.1 DEFINING THE PROBLEM

To start we defined the problem which was to make an exhibit based on the course and client requirements on the science of green energy for middle and high school students. The exhibit will serve in place of a museum which they don't have access to.

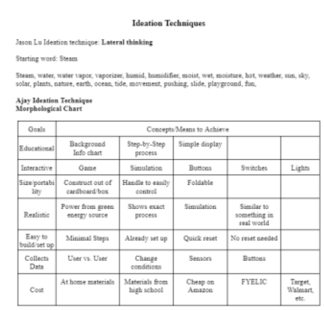
The exhibit must educate the users while maintaining a balance of education, fun, and interactivity. The amount of educational information and content presented to the users needs to be appropriate. Specifically, the educational information provided must be organized and clear to ensure the user is able to understand it in a short amount of time. In order to make sure the user gets the most out of this learning experience, the exhibit must accurately model or include how green energy works and should be realistic to how it is used in the real world. The way the user learns from this exhibit is also a point of focus, as the exhibit needs to make sure the user is engaged and learns based on the process of exploration and interaction with it. This process of exploration must not be too complex so the main focus will still be learning about the science of green energy rather than figuring out how to function the exhibit.

There are specific requirements that need to be met, specifically the exhibit must be small and cannot exceed 28 inches long and 36 inches wide. The exhibit must be easy to set up allowing for the exhibit to be easily transported from school to school. Additionally, the exhibit must have the ability to be assembled and disassembled without extreme effort and should take no more than 15 minutes to do so. The client has set a limit of $100.00 for the prototype and $1,000.00 for the completed exhibit. Making sure the users learn from the exhibit is important, but also making sure money is efficiently spent so the total costs do not exceed 100 dollars. The quality and effectiveness of the overall project will ensure both the client and group benefit.

9.2 RESEARCH, IDEATION AND DECISION-MAKING PROCESS

We started by researching all the different types of green energy. This includes hydroelectric power, tidal power, geothermal power, wind energy, biomass energy, and solar energy. By dividing the six types of renewable energy we were able to research multiple types of green energy at the same time. Our research centered around gathering general important information pertaining to each type of energy and finding existing exhibits to better understand what a potential exhibit could look like. After conducting research, we began the ideation process, we decided to use a multitude of different ideation techniques. These techniques included lateral thinking, a morphological chart, and analogies. These ideation techniques can be found in Figure [30] below.

Figure 111. Ideation Techniques Utilized



Ideation Techniques

Jason Lu Ideation technique: **Lateral thinking**

Starting word: Steam

Steam, water, water vapor, vaporizer, humid, humidifier, moist, wet, moisture, hot, weather, sun, sky, solar, plants, nature, earth, ocean, tide, movement, pushing, slide, playground, fun,

Ajay Ideation Technique
Morphological Chart

Goals	Concepts/Means to Achieve				
Educational	Background Info chart	Step-by-Step process	Simple display		
Interactive	Game	Simulation	Buttons	Switches	Lights
Size/portability	Construct out of cardboard/box	Handle to easily control	Foldable		
Realistic	Power from green energy source	Shows exact process	Simulation	Similar to something in real world	
Easy to build/set up	Minimal Steps	Already set up	Quick reset	No reset needed	
Collects Data	User vs. User	Change conditions	Sensors	Buttons	
Cost	At home materials	Materials from high school	Cheap on Amazon	FYELIC	Target, Walmart, etc.

The first technique was lateral thinking. This allowed the team to explore ideas in a broader and more general way. Any words that came to mind would be written down one after the other. This technique gave the team the opportunity to come up with ideas without worrying about quality. Next, the morphological chart allowed the team to prioritize the design goals. Each idea written down would align with a specific goal. This allowed any ideas generated to be specific to each goal. Finally, the analogies technique was used to narrow the scope of each idea, allowing us to come up with specific design ideas. Combining ideas from each different ideation technique allowed the team to develop designs that are goal specific. Along with the ideation techniques, the team discussed a list of several values that we all held and wanted our design to reflect. This list included: Creativity, Personal Development, Competition and Gaining Wisdom. Throughout individual tasks, each team member made sure to incorporate as many of these values as possible. This would aid us in producing a design that reflects our values.

After the ideation process, we created goals for our exhibit and a rank order chart as shown below and in Appendix B.

Table 8. Rank Order Chart

	Educational	Interactive	Size/portability	Realistic	Easy to Build/set up	Collects data	Cost	Total
Educational	-	1	1	1	1	1	1	6
Interactive	0	-	1	1	1	1	1	5
Size/portability	0	0	-	1	1	1	0.5	3.5
Realistic	0	0	0	-	0.5	1	0	1.5

We then each individually generated two unique ideas for exhibits after establishing the group goals along with their respective ratings through a rank order chart. The group narrowed down which design was best based off of a KTDA Chart shown below and in Appendix B.

Table 13. KTDA Chart

Group Decision Matrix Ratings for Design Goals

	Educational		Interactive		Size/portability		Cost		Realistic		Easy to Build		Collects Data		Total
Weights	6.5		5		3.5		3.5		1.5		1.5		1		
Geothermal Exhibit (Jason)	9.50	61.75	5.00	25.00	9.50	33.25	7.75	27.13	7.75	11.63	8.75	13.13	1.50	1.50	173.38
Tidal Exhibit (Jason)	8.75	56.88	8.75	43.75	8.00	28.00	7.00	24.50	7.75	11.63	8.75	13.13	1.50	1.50	179.38
Hydroelectric vs. Solar cars (Ajay)	7.75	50.38	5.50	27.50	7.13	24.94	6.00	21.00	5.75	8.63	5.38	8.06	4.25	4.25	144.75
Solar Tug of War	7.75	50.38	10.00	50.00	8.75	30.63	8.25	28.88	7.25	10.88	8.00	12.00	8.50	8.50	191.75

The highest scoring design was the Solar Powered Tug of War as shown below in Figure [6]. This design scored the highest mainly due to its high scores in the two most heavily weighted categories: Educational and Interactive. However, we also planned on having a backup option just in case we needed to change from the Solar Powered Tug of War design. The backup option was the second-best scoring design and was a tidal simulation concept and is shown below in Figure [15].

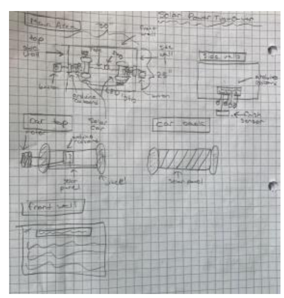


Figure 115. Solar Powered Tug-of-War by Ajay Haridasse

This exhibit features a tug of war between two solar energy powered carts with a rope connecting the two, with Arduino sensors and LEDs on the side walls to increase the power of the solar panels. The LEDs would be coded to turn on the more the user presses the button on that side, making it player vs. player, and the game stops when the sensor on the side wall is reached. The front wall features background information on solar energy as well as how the game works between the users. Challenges in using this include figuring out the easiest way to reset the game as well as finding materials to use for the base of the carts, and solar panels. Coding the movement of the carts will not be too difficult as it just requires it to turn the motors of the carts and then stop once one of the carts reaches the final sensor; however, determining the speed and testing values will be necessary which could be challenging.

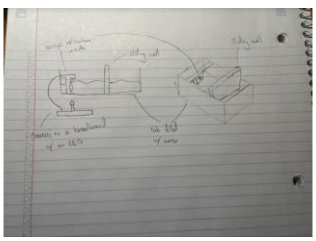


Figure 14. Tidal Power Exhibit by Jason Lu

This design is a replication of what a tidal power generator would look like. The exhibit is contained within a big tub filled with water. The sliding wall is operated by the user. When pushed, the sliding wall will move the water and simulate waves. There is a barrage fixed to one end of the tub that represents the barrage in a real tidal generator. This is a simulated tidal generator, and when the sliding wall is pushed, the LED will light up signaling that power was generated from the waves.

9.3 PLANNING

1For the planning of our prototype we reviewed Professor O'Connell's feedback and we decided that modifying our design would be the best option. The original design was essentially a user vs. user. button mashing game that powered one solar-powered car to tug another solar-powered car with there eventually being a winner once one car reached a certain point. Although this idea was interesting and incorporated user interaction it was too complex and would be difficult to actually create. The button mashing aspect, whether or not one car would be able to pull another, figuring out a way to reset the game once it was over, and the complexity of the solar-powered cars were all problems the group could not address with the time available so we decided to go a different route.

In the modified game, there are two simple cars attached to a string that are each winded up and down a ramp by a 360 motor. The game starts off with the users being prompted true or false questions through a MATLAB app while the cars are positioned at the bottom of the ramp. The motor starts off by rotating at a very slow speed, and as the motors rotate, the cars are slowly pulled up the ramp. If a user gets a question right, their corresponding motor will begin to turn faster, resulting in their car being brought up the ramp faster. Along with the motor speed increasing when a player gets a question correct, LEDs set up next to a fake solar panel will light up, giving the user the impression that the motor is powered by the LED and solar panel. If a user answers the question incorrectly, the motor speed will not change and more LEDs will not be lit up. The more correctly answered questions, the faster the motor will wind the cars towards the top of the ramp, and once one of the cars reaches a certain point first, the corresponding user will be deemed the winner. Once this occurs, this will then be displayed and wind the cars down by turning the 360 the other way all the way back to its initial position. Following this, the MATLAB application will reset and two new users will be able to try the exhibit game

9.4 RAPID PROTOTYPING AND PROOF OF CONCEPT

The next process involved rapid prototyping and the beginning of the construction phase of the project. We first began this by starting with deciding on 3D printing servo motor holders and dowels. The designs can be found below the blue holder and dowel are the first design and the purple holder and dowel are the final design. The key differences are the size and positioning of holes on both parts.

Figure 117. 3D Printed Servo Motor Holders and Dowels (First design on left and final design on right)

Although these were small changes these were necessary changes and helped the overall functionality of our game. We also hot glued a servo motor attachment to the dowel in order to have a solid connection to the servo motor to cause the dowel to spin thereby coiling the string around it and pulling the car up the ramp. In this stage of the project we created our prototype to 60% as shown below and more photos are available in Appendix H.

Figure 119. Front View of Button Board Box

Figure 121. Isometric View of Ramp

During this proof of concept stage our design and ideas for intended function were put on display. Our game would utilize a MATLAB application that will prompt questions to the user, with the user being able to answer true or false with their corresponding buttons. Our game requires two users to play but only one user is needed to display that the exhibit will be able to function.

At this point we were missing a few aspects, but the missing aspects are purely to enhance the user's flow through the exhibit and the aesthetic meaning they are not necessarily needed for our game to work, but will be needed to fully complete the game. In our complete exhibit, we plan on having numerous questions but for this part of the project we have two for now to show the function of what happens when a question is answered correctly and incorrectly. Along with this, in our user interface we have included a start, stop, and reset button for our proof of concept, but we intend on including an extra physical button for the start and reset on our exhibit as well as a photoresistor to trigger the motor to stop so the user interface is only for reading the questions and corresponding feedback. Additionally, the led strip along with the non-functioning solar panel behind the servo motor as well as the informational text and instructions to play on the keyboard cover are not included as although these are needed to complete our project, they are not needed to show its function in relation to user interaction.

In the proof of concept demonstration the game is started when the user hits the start button on the user interface, which turns the motor on and rotates it at a very slow rate. This motor rotation causes the string to wind up on the dowel which in turn pulls the car up the ramp as it is attached to the other side of the string. The first question is prompted to the user with the answer being true, so when the user hits the physical true button, the user interface displays that the question is correct, and the motor begins to turn faster. Following the interface displaying the answer was correct, the next question is then prompted to the user, with the correct answer being false. In the demonstration, the user hits true despite the true answer being false, but this shows the motor not changing in speed, which then also displays that the answer was wrong on the user interface. In the demo, the game is stopped when the stop button is pressed on the user interface, but as stated before the motor will stop when triggered using a photoresistor. When the photoresistor reads a lower light level as a result of the car passing near it, the motor will then stop. Following the stoppage, the user hits the reset button which then turns the motor in the other direction, and using the help of gravity the car winds back down to the bottom of the ramp so the game can start over. The speeds at which the motor turns to wind the car up the ramp as well as unwind it back down still need to be adjusted, but through trial and error the group will find out what works best for the flow of the game and reset.

9.5 GALLERY WALK AND FEEDBACK COLLECTION

Our prototype was 90% complete for the gallery walk our design is shown below and in Appendix H.

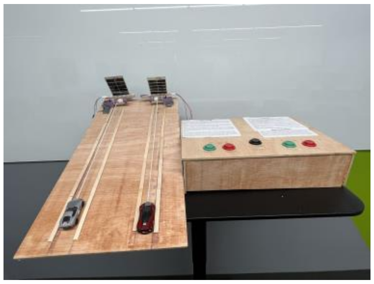


Figure 74. 90% Complete Solar Energy Exhibit

Figure [10]. Front View of 90% Complete Exhibit

The gallery walk overall went poor because of our code not functioning properly. However; despite this we obtained valuable feedback which allowed us to see what we needed to improve upon for our final prototype. The coding needed to be refined, specifically there needed to be a button debounce implemented to prevent user's from button mashing and causing the program to malfunction. Additionally, the values for motors and photoresistors would need to be changed for the reset aspect of the exhibit. Aside from the code, making sure the prototype was fully stable was necessary because during the gallery walk the back panel where the laptop was supposed to be placed into was partially disconnected. After the securing of the design we planned to finish the aesthetics in the next stage.

9.6 FINAL PROTOTYPE TESTING AND EVALUATION

To complete our final prototype we needed to refine the code, work on the aesthetics of the design, shorten educational text and game instructions and disperse them onto the user interface of the MATLAB application. We also added pictures to the top of the box and on the user interface of the app. Most of these changes were to make our design aesthetically pleasing and more practical for the users of the exhibit. Finally we tested for the exposition to ensure all values of code and physical components were set up appropriately and everything was functioning.

The feedback we received from the exposition was mostly positive. We manually collected data which consisted of the time of usage of our exhibit and comments user's disclosed to us about our exhibit. Our exhibit's time usage averaged to around 45 seconds although our exhibit was relatively quick we thought it was appropriate presented that 3rd and 4th grade students were users and accommodating for their short attention spans was necessary. As mentioned earlier feedback we received was mostly positive and users stated that our exhibit was fun, cool, a good simulation of solar energy, and overall a good idea see Appendix D for all data manually collected during the expo.

9.7 MY CONTRIBUTIONS

Throughout this project I was a significant contributor in the ideating, planning, constructing, and resource allocating of the project. Throughout the milestones aside from when there was a designated project manager I did the majority of the resource tracking. Starting off with milestone 1, I conducted research on hydroelectric power and tidal power. In milestone 2, I created two exhibit ideas my ideas were a windmill exhibit and a hydroelectric power/ watermill exhibit. These two exhibits can be found below in Figures [7] and [8].

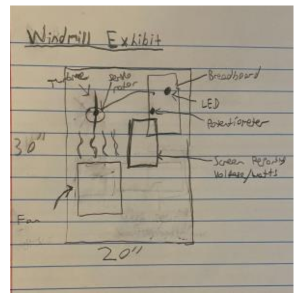


Figure 123. Windmill Exhibit by Andrew

This exhibit simulates what a windmill does to produce electricity. Included in this design is a fan which blows air on a turbine connected to a servo motor which rotates and displays voltage created by the rotation of the motor. This design exhibit is meant to simulate how wind turbines work in the real world. The fan represents wind that would blow on the wind turbine and cause the turbine to rotate causing a generator to generate electricity. As this design is a simulation this design does not include a generator which would actually generate the electricity but it includes all other parts commonly found in windmills to replicate and represent an actual windmill and its function. Included in this exhibit would also be an LCD display screen to display the voltage that would be created by the wind turbine. This exhibit would be framed on a 20" wide x 30" long flat cardboard platform. Educational text can be incorporated and included around the components of the exhibit explaining the individual components of the exhibit and the processes of windmills.

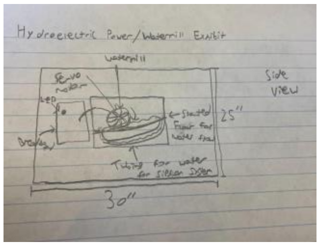


Figure 125. Watermill Exhibit by Andrew Hedberg

In this exhibit the use of hydropower is present through the use of a watermill design. The water is placed in the plastic box on the top of the slanted floor allowing for the water to flow down the slanted surface and flow into the watermill design causing the watermill to turn and for the connected servo motor to generate energy. The water that passes past the watermill goes to the lowest elevation of the slanted surface and fills up a tube that leads to the highest elevation allowing for the design to serve as a siphon pump. This design also could include a screen from the sparkfun kit displaying the voltage/watts created by the watermill like in the windmill exhibit.

The main critiques of the windmill exhibit were that it was not a unique design and would be easy to create. The main critiques of the hydroelectric power/ watermill exhibit were that it would be hard to display and contain the water making it difficult to build and not feasible. Therefore, we moved towards using Ajay's solar powered tug of war exhibit idea.

In milestone 3, after our final exhibit was selected which was the Solar Powered Tug of War exhibit, I completed two CAD drawings and the photo log for the milestone of our cardboard prototype. Shown below are my CAD drawings of the exhibit in display and transport mode.

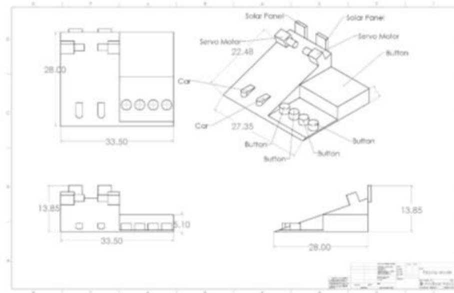


Figure 127. Display Mode CAD Drawing by Andrew Hedberg

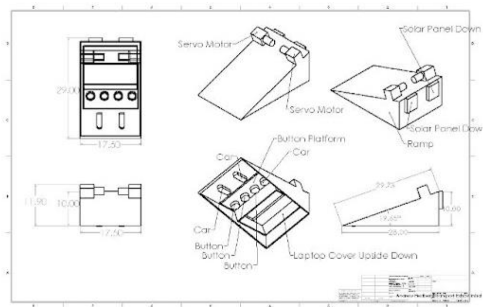


Figure 129. Transport Mode CAD Drawing by Andrew Hedberg

For milestone 4, I dimensioned and then constructed the wood ramp and button board box. I also wrote some aspects of the memorandum like the implementation documentation and created the photo log of our 60% complete prototype.

During milestone 5, I 3D printed the servo motor holders and dowels a 2nd and final time, I laid out where all components needed to go in SolidWorks in a ramp layout plan part and drawing, see Appendix C. After this I drilled out two holes for photoresistors and for servo motor wires and created the laptop holder slot and laptop shelf. I also drew out two wood pieces for a red vest to cut out for the

LED strips to rest on. Then I assisted with the hot gluing of the popsicle sticks and I hot glued the wood piece for the LED strips to rest on to the servo motor holders. Finally, I taped the non-functioning solar panels, servo motor holders, string to cars and dowels, and LEDs to complete the 90% prototype in preparation for P2M5 and the gallery walk.

For P2M6, I was responsible for finishing part of the remaining 10% of the project ensuring the design was first secured and stable then acquiring acrylic paint and paint brushes, painting the project, and finally hot gluing all components like the servo motor holders and string to dowels and hot wheel cars to see the final prototype see Appendix H.

For P2M7, I added the appendices and reviewed the abstract and other group sections of the 80% complete technical report.

FELLOWSHIP OF WIZARDS

10 FINAL DESIGN

10.1 FINAL DESIGN

Figure 131. Display Mode of Final Design

The final design consists of three separate pieces including a computer. The final design of the Solar Energy Race exhibit is shown in figure [39].

Figure 133. Left View of Ramp

Figure 135. Top View of Ramp

The first is a 24 inch long, 12 inch wide, and 10-inch-tall ramp which is hollowed out underneath and does not have a back wall. The ramp component of the exhibit is shown in figures [40] and figure [41].

Figure 137. Side View of Keyboard Cover/Button Board

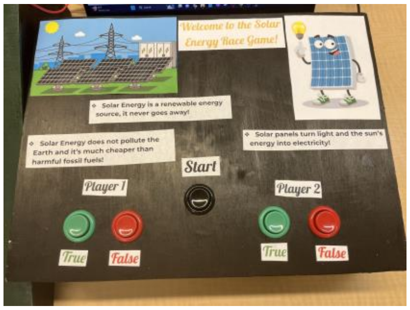


Figure 139. Top View of Keyboard Cover / Button Board

The second piece, the keyboard cover and button board, is a 12 inch long, 14 inch wide, and 6-inch-tall bottomless box shaped piece with a slot on one side. The keyboard cover / button board and all of its components are shown in figures [42] and [43]. The slot on the side contains a wooden shelf that is 8 inches long attached to the box just before the opening so a computer can rest on it. Also featured on the board are 5 holes for buttons, with 4 of them being equally spaced in a horizontal line that is parallel to the wide edge of the board, with one buttonhole centered in the middle of them but an inch further from the wide edge of the board.

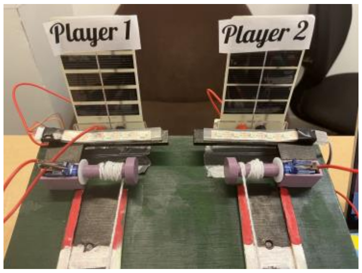


Figure 141. Top of Ramp Holding the Solar Panels, Servo Motors, and LEDs

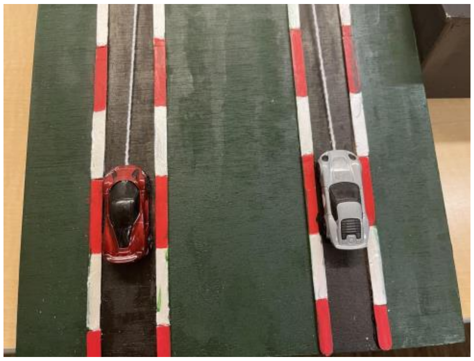


Figure 143. Hot Wheels Cars Attached to String

The ramp contains multiple key components on its inclined surface: Two non-functioning solar panels, two servo motor holders with servo motors in them, two 3D printed dowels attached to each servo motor, a string attached to each dowel with hot wheels cars attached at the other end, and holes in the ramp under the servo motor holders and at the painted finish lines for the wires and photoresistors. The components featured on the top of the ramp and the hot wheels cars that are attached to the other end of the string are shown in figure [44] and figure [45].

On the top of the ramp there are two non-functional solar panels, each placed 3 inches from the center of the wide edge of the ramp on the uppermost edge. The left solar panel is labeled as Player 1's side and the right are labeled as Player 2's.

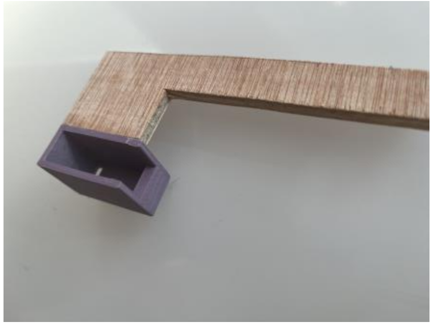


Figure 145. Servo Motor Holder

In front of the solar panels are two servo motor holders with wooden pieces attached to the upper edge of them on the side closest to the solar panels. Each servo motor holder is a hollowed out open-ended box that allows the servo motors to fit directly into them with a hole for the wires out of the bottom. The servo motor holder is shown in figure [46]. These wooden pieces were attached so LED strips could lay on them and be closer to the solar panels. Each servo motor is placed into each holder with the spinning piece facing the inside of the ramp.

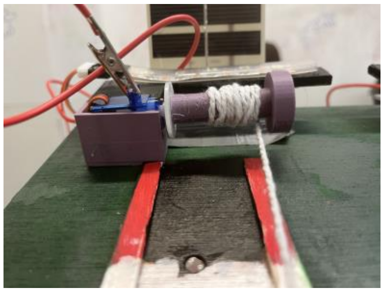


Figure 147. Servo Motor and Dowel with String Attached

Each servo motor has its own dowel that each has a piece of string wound on it with one edge of the string glued to the dowel, and the other glued to a Hot Wheels car. These pieces all connected together can be seen in figure []. The ramp also contains two popsicle stick bordered tracks that start at the bottom edge of the ramp and go up to where the servo holders are placed, with the width between each popsicle stick border being slightly larger than the width of the Hot Wheels Car. Each Hot Wheels car is placed on each set of tracks. Holes in the ramp are made at each painted finish line for a photoresistor to go through as well as under each servo motor holder for the wiring to go under the ramp.

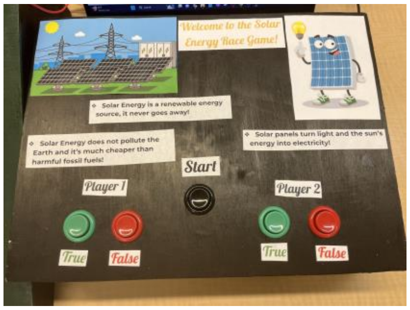


Figure 149. Top View of Keyboard Cover / Button Board

For each of the buttonholes on the keyboard cover / button box surface, there are corresponding game buttons that fit into them. On the surface, the row of four buttons has alternating green and red buttons, with the button slightly above being black. The entire keyboard cover / button board surface is shown in figure [43]. The left side of buttons is labeled as Player 1's and the right are labeled as Player 2's with the black button being labeled as the start button. On the other half of the button surface contains solar energy information, the name of the exhibit as well as a few pictures.

Figure 151. Display Mode of Final Design

To set up the exhibit for display, the back edge of the ramp and the back edge of the button board are lined up so they are collinear, with the computer being placed on the shelf of the button board. The screen of the computer is perpendicular to the surface of the button board and presents the MATLAB graphic user interface for our exhibit. The Arduino RedBoard and Breadboard are connected to the computer with a majority of the wiring hiding beneath the ramp and button board surface. Extension wires are used so each component on the ramp and button surface can reach where they need to be. The exhibit set up in display mode is shown in figure [39].

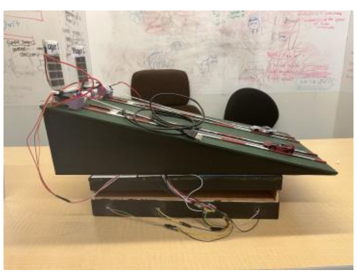


Figure 153. Transport Mode of Final Design

In display mode the exhibit measures 34 inches wide, 24 inches long, and 10 inches in height. When in transport mode the ramp is placed directly on the surface of the button board and fits within a tote bag. The exhibit set up in its transport orientation is shown in figure [50].

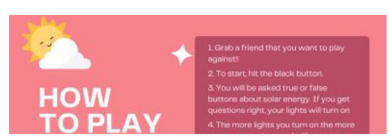
The ramp and keyboard cover / button board were constructed out of wood and is shown in the bill of materials in Appendix K. The bill of materials also displays the quantities, values, and costs of each individual component referenced in this section as well as where we acquired them from.

10.2 USER INTERACTION

Figure 155. GUI Start Screen

The exhibit is a solar-powered race between two users. When users approach the exhibit, a start screen will prompt them to press the start button. The first screen of the user interface that is shown to the users is shown in figure [51].

Figure 157. GUI Instructions Screen



After pressing the start button, an instruction screen will explain the game. Once the user's read this through they will then have to press the start button again to begin. The second screen of the user interface that displays the instructions is shown in figure [52].

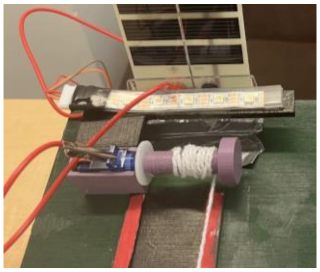


Figure 148. Servo Motor and Dowel with String

One LED on each user's LED strip will light up, and the servo motors at the top of the ramp will start spinning slowly. As they spin, the dowel turns and pulls the Hot Wheels cars at the bottom of the ramp towards the top of the ramp. The dowel with the string wrapped around it and the LED strip at the start of the game are shown in figure [47].

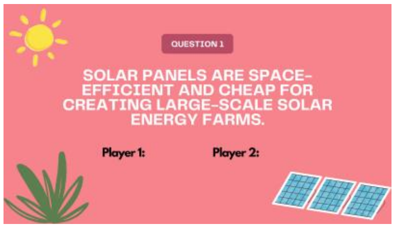


Figure 161. GUI Question 1 Screen

Users are then presented with true/false questions on the screen, which they answer with buttons in front of them. The user interface with the first prompted question is shown in figure [53]. If the answer is correct, another LED will light up, and the servo will spin faster, pulling the car up the ramp faster. If the answer is wrong, the servo will not change speed. This cycle continues until a user's car reaches the top of the ramp.

The LED lighting up demonstrates more energy being generated by the solar panel which turns the servo motor faster.

Once both users have answered the question displayed, the screen will change to the next question. This cycle of users answering questions and the LED and servo reacting accordingly will continue until a user's car reaches the top of the ramp. The questions are the same five questions for every run of the game and are presented in the same order.

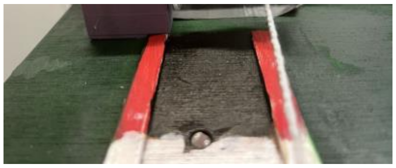


Figure 163. Photoresistor in Finish Line

At the top of the ramp, there is a photoresistor embedded into the finish line for each track. The photoresistor shown at the edge of the white finish line is shown in figure [54]. This photo resistor constantly checks the light level to see when a car drives over the photoresistor. When the car drives over this, it crosses the finish line, so the photoresistor will read a significantly lower light level to signal the end of the game.

Figure 165. GUI End Screen

Whichever player's corresponding car reaches their side's finish line, or their side's photoresistor first, wins the game. The motor will stop once the car is covering their photoresistor and the screen will display the winner. The screen of the user interface that displays the winner of the game is shown in figure [55].

The other user's servo motor will keep pulling the car up until that second car also crosses the finish line and covers their photoresistor. Once the other side's car crosses their finish line and both photoresistors are covered, both servos will rewind at the same speed until both cars are reset to the bottom of the ramp. The rewind is done at a set speed for three and a half seconds so that both cars are set back to where they started.

The MATLAB app will also reset to the start screen thus resetting the game making it ready to be played again. A detailed flowchart of the user interaction can be found in Appendix G.

JASON LU

11 DISCUSSION/ANALYSIS

11.1 FINAL DESIGN

The final exhibit was successful in meeting the constraints and requirements. The design was compact and fit into the tote bag easily. It was also simple to set up and could withstand continuous usage throughout the expo. As evidenced by laughter accompanied by repeated playthroughs, the exhibit was both fun and engaging. However, there were some areas that could have been improved. The exhibit did not provide the most educational experience, as some children did not take the time to read the fun facts or even the questions.

11.2 STRENGTHS AND WEAKNESSES

The exhibit had several strengths. It worked well and was very engaging, often leading to users wanting a rematch. The exhibit was also colorful and very child-friendly, which added to the fun experience.

However, there were also some weaknesses. The exhibit was a little too wordy for younger children, and many kids did not want to read the questions and simply guessed at the answers. Additionally, the buttons were old and did not work very well, which made some people think that the exhibit was broken. The exhibit was also not the most educational as the game aspect took away from the educational aspect. Some children were more focused on pressing buttons and making the car go up the ramp rather than reading the questions and learning about the topic.

Overall, it is important to take into consideration the age range and attention span of the target audience when designing exhibits.

12 CONCLUSION

12.1 TAKEAWAYS

Some takeaways from our project are that we need to be conscious of what children are willing to read and cater the exhibit accordingly. It is also important to test the project in as many ways as possible to catch any potential issues. For example, during the gallery walk, we discovered that the MATLAB game immediately broke when the buttons were repeatedly pressed in quick succession, which was something I had not accounted for. Additionally, it's important to obtain high-quality materials to ensure the durability of the exhibit. In our case, the cheap quality of the wood used caused parts of the exhibit to break during construction, which led to rebuilding that wasted time and resources. Finally, using old buttons and servos resulted in them not functioning as well as they should have.

12.2 RESULTS

Overall, the final exhibit was successful, as there were no issues with its continued usage during the expo, and we did not have to reset the race at all, which was a huge accomplishment in producing an exhibit that does not require any moderation. The design did a great job in providing an interactive and fun experience, as many children were laughing while using the exhibit. However, while the exhibit excelled in being interactive, it did not perform as well in providing an educational experience. We overestimated the children's willingness to read, as some did not read the questions or the fun facts on the button board.

13 RECOMMENDATIONS

If I were to make changes to the exhibit, there are several improvements that could be made. First, I would simplify the questions to make them less wordy and make the instructions more straightforward. Additionally, adding music or sound effects could make the experience more enjoyable for the children. Getting newer buttons would also be beneficial, as the current ones are old and require a lot of pressure to activate, leading to confusion and frustration among users. To encourage reading, I would consider moving the fun facts from the button board into the MATLAB app. Finally, rearranging the setup by placing the racetrack between the two players and the display at the top of the ramp could improve the exhibit's usability. This would allow players to watch the race while answering questions.

15 LESSONS LEARNED

13.1 CONTRIBUTIONS

Throughout Milestones 5-7, I was responsible for all the code and electronics. I wrote the code and created the wire diagram in Appendix E and F respectively. Additionally, I wired the electronics in the final iteration of the design.

As part of the user interface, I designed and created fun and colorful graphics using Canva, an online infographic creator.

During the gallery walk, several issues within the code were identified, such as excessive button inputs breaking the game and the game not ending if either user did not get any questions right. I was responsible for fixing all the bugs in the code.

To ensure that the final prototype was working as intended, I conducted extensive testing right before the final expo. This included calibrating each servo motor to ensure that they spun at the same rate and making sure that the game worked even if the users simply mashed the buttons. I also replayed the game over and over to make sure that the game could be replayed without anyone having to manually reset it after every round.

13.2 RESOURCES

Our group did meet the budget and the materials we acquired personally were the 2'x4' plywood, 2 hot wheels cars and acrylic paint.

Depending on the milestone, I devoted around 10-20 hours a week to this project.

This experience made me a lot better at managing my time and looking at future assignments. This project along with all the other assignments from Cornerstone alone has forced me to become less of a procrastinator and more proactive when it comes to completing assignments.

13.3 REFLECTIONS ON LEARNING

I learned how to code a lot better from this project. Prior to this class, I essentially had no experience with any coding. I had to teach myself how to code a full interactive game in MATLAB. I am very proud of how the game turned out as it worked wonderfully in the expo. This experience really taught me how to problem solve especially in coding assignments. My newly acquired knowledge of MATLAB and problem solving will definitely benefit me in my future career.

13.4 REFLECTIONS ON WORKING IN A TEAM

This project made me a much better leader. There were many times where the project manager at the time was not so comfortable in their leadership role. This meant that I had to step up and organize the group to ensure that we were still progressing and on track to turn in the milestone on time.

A challenge that I overcame was having an unreliable group member that suddenly dropped the class. This meant that the rest of the group had to burden more of what used to be his work. While this was very inconvenient, I am proud of my group for pushing through and producing a working project at the end anyways.

One aspect of teamwork that I still have to work on is being more straightforward with my group mates. There were times where one or two group members did not get their individual work done on time which hindered everyone else's ability to complete other parts of the project. In those instances, I had the chance to speak up and tell them to work on completing their work on time, but I did not as I did not want to create conflict.

I would describe my leadership style to be not so controlling and more flexible. I would distribute the work as I saw fit and cover whatever had not been assigned.

The team overcame adversity by working hard and communicating with each other. This communication was also our biggest asset as it allowed us to better work together as a team rather than a group of individuals.

If I could go back to the beginning of the semester, I would try to be a little more assertive as I feel that I may have been a little too lenient on some members in the group. I would also make sure to start each milestone a day or two earlier so we would not be rushing to complete it the night it was due.

If I had more time, I might have liked to add some sound effects or music. I feel that this might make the experience more enjoyable for the children.

ANDREW HEDBERG

14 DISCUSSION

14.1 FINAL DESIGN RESULTS

For exhibit requirements, our project fit within the budget and both the display and transport mode requirements. Our project is 34 inches in width, 24 inches in length, and 10 inches in height for display mode and when in transport mode it fit within the tote bag meaning our exhibit was portable and could easily be traveled from different locations easily. Additionally, it only takes on average about two minutes to assemble and disassemble the entire exhibit which obviously meets the 15 minute time requirement and only one person is needed to transport and assemble and disassemble the exhibit. The exhibit includes more than 2 SparkFun Inventor's Kit components, more than 2 interactive elements, and used 3D printed parts thereby making us successful in meeting the course and client requirements.

During the expo we watched users as they played through and experienced our exhibit. In order to analyze the effectiveness, the group took note of the unexpected errors and times we had to troubleshoot our exhibit, the time of use by each group of users as well as what question the game ended on, and the comments we received about our exhibit as a whole.

Overall, our exhibit performed well throughout the entirety of the expo despite a few minor things that we did not realize we would encounter as well as things that were out of our control. Issues we found that only occurred once was when the start button was pressed an additional time after the users were already prompted with true or false questions as well as the buttons having to be pressed very hard or multiple times for the computer to read due to how old the buttons were. Along with this, we found that in the case that a user does not get any of the questions right, the car was never able to cover their sides photoresistor to end and reset the game, which forced us to manually do so.

To analyze how well the users were learning, the group used the time of use by each set of users as well as what question the game ended on to analyze this. Since the cars reach the top of the ramp the more correct the users are throughout the game, we found that the shorter amount of time the game took to end meant the users were answering questions faster and more correctly, leading to the motors speeding up and ending the game faster. Overall, using a random sample of 10 of the 21 total games, the average time of play was 45.97 seconds with the average of the question ending being 3.73. Along with this sampling of data, we also found that when users came back to play again the time it took for the game to end was shorter, considering they already had seen the question set and knew the answers, showing they remembered from their previous attempt.

Aside from numerical data, we also recorded comments we received on our exhibit during and following completion of users participating in the exhibit. Users stated how they liked the aesthetics of the exhibit, commenting on both the presentation of the MATLAB app as well as the ramp and the car portion of the exhibit. We also received comments regarding the flow of the game, as they liked the idea of racing against someone as well as how clean the reset is with the cars being unwind back to the bottom. The comments received were mainly positive which is a good and bad thing, as not getting any negative comments may be due to users not wanting to bluntly tell us.

14.2 STRENGTHS AND WEAKNESSES

There were many strengths and weaknesses with our design. Starting with the strengths the design attracted users with colors that resembled a race track and the colorful MATLAB application GUI see Appendix H. Based on our data manually collected at the expo our exhibit we believe was appropriate for the 3rd and 4th graders attention spans because our exhibit was relatively quick and took most users from anywhere between 30 seconds to 1 minute to finish. Feedback we received was mostly positive saying our exhibit was fun, cool, a good simulation of solar energy, and overall a good idea see Appendix D for all data manually collected during the expo. The primary weaknesses of our design include our wiring in the back of exhibit was messy, we didn't have a method for automatic data/ feedback collection, the game aspect may have taken away partially from educational aspect of exhibit, and last but not least since our exhibit was a two player game and not a one player game individuals could not play by themself so this was discouraging and occasionally led to awkward situations where the user couldn't do the exhibit and left.

15 CONCLUSION

15.1 TAKEAWAYS

Some key takeaways for this project include overcoming adversity, and being highly adaptable and realistic. Our group overcame adversity because one group member contributed less throughout the project and eventually left our group which caused us stress and added more work for three of us to do. Because of our strong group dynamic we stayed positive and were able to get all work for our project and each milestone successfully completed. We became highly adaptable because early on in the project deciding on an idea for a project was difficult and our initial ideas were too complicated. As a result, we adapted to the time and resources available to modify our project into a simple true or false game with simulation of solar panel usage and not actually generating electricity with the solar panels. This leads to the last takeaway of being realistic because throughout the project each of us made realistic expectations for each other to complete different parts of our project. For example, I was expected to complete the majority of the construction, Ajay was expected to complete the majority of the writing in memorandums and assist with construction, and Jason primarily worked on the coding for the project. To recap the biggest personal takeaways I will also be taking away from this project are to not give up, work with your group members and not against them, and to break down tasks into smaller pieces in order to prevent getting overwhelmed.

15.2 RESTATEMENT OF RESULTS

Overall, the design was fully functional and met all course and client requirements. However, there were a couple of instances where we needed to intervene the first being to fix the reset code because once the reset button was pressed during the question prompting stages of the game, the game would stop functioning. The second instance where we needed to intervene was when a user didn't get any questions correct causing the game to take a considerable amount of time to reset therefore covering the photoresistor to manually reset the game was necessary. Aside these two instances where we needed to intervene the project was able to serve as a self-standing educational exhibit on solar energy.

15.3 CONCLUDING REMARKS

In conclusion, our group was able to work through the engineering design process to develop an educational exhibit on the science of solar panels. This educational exhibit was designed with the consideration of the client and course requirements. There were many positive and negative aspects to our final design just like there were many ups and downs in the process throughout our project. Despite these aspects we successfully completed the project and were satisfied with our end product.

16 RECOMENDATIONS

16.1 ENHANCEMENT OF PROJECT

Given more time and resources there could be a lot of ways we could enhance our project. Our project can be enhanced by adding more features/ components to our code and final prototype, and by changing certain aspects of our construction process and design as well.

The first way to enhance our project could be by adding sound effects, music, or narration that plays when the exhibit is not being used, is being used, and/or in response to users responses. This could attract users to our exhibit, explain why users got questions wrong, and can add another fun element to the exhibit being able to listen to music. The second way to enhance our project could be through implementing a leaderboard on the MATLAB application GUI showing fastest times to win the game which would increase competitiveness of users and increase their desire to know the answers to the questions. A third way to enhance our project could be by implementing a better internal way to hide the wiring in the back of exhibit and by adding a back panel to the ramp to give our design a cleaner look from the back view. A fourth way our project could be enhanced could be by in addition to our current design with educational information also creating a tri-fold poster board and adding educational information and graphics on solar panels to that. This would allow us to then make our MATLAB application switch up the questions randomly from a large pool of questions every time the users play the exhibit which could lead the users to learn even more about solar panels.

Some ways our design could be enhanced by changing some aspects could be by using more expensive wood because the wood we used was pretty inexpensive. Additionally, instead of saw cutting wood pieces, laser cutting to precisely cut the wood would yield a cleaner look for our design and would ensure the designs dimensions are more exact. Finally, instead of using wood glue to bring together wood pieces, drilling screws could serve to be a more durable option.

All of these enhancements would definitely improve our final design. However, as mentioned earlier it would require more time and resources and although we thought about some of these enhancements throughout the process because of those time and resource constraints we were not able to implement the enhancements to our code and final prototype, construction process, and overall design.

17 LESSONS LEARNED

17.1 INDIVIDUAL CONTRIBUTIONS

Throughout all milestones I played a key role in the overall construction and planning of our project. Specifically for milestones 5-7 this remained true. During milestone 5, I 3D printed the servo motor holders and dowels a 2nd and final time, I laid out where all components needed to go in SolidWorks in a ramp layout plan part and drawing see Appendix C. After this I drilled out two holes for photoresistors and for servo motor wires and created the laptop holder slot and laptop shelf. I also drew out two wood pieces for a red vest to cut out for the LED strips to rest on. Then I assisted with the hot gluing of the popsicle sticks and I hot glued the wood piece for the LED strips to rest on to the servo motor holders. Finally, I taped the non-functioning solar panels, servo motor holders, string to cars and dowels, and LEDs to complete the 90% prototype in preparation for P2M5 and the gallery walk.

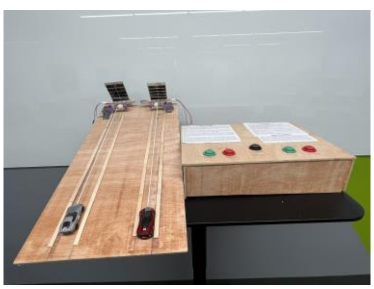


Figure 74. 90% Complete Solar Energy Exhibit

For P2M6 I was responsible for finishing part of the remaining 10% of the project ensuring the design was first secured and stable then acquiring acrylic paint and paint brushes, painting the project, and finally hot gluing all components like the servo motor holders and string to dowels and hot wheel cars.

For P2M7 I added the appendices and reviewed the abstract and other group sections of the 80% complete technical report. For P2M5 and P2M6 I also contributed to the memorandums, attachments, and resource tracking.

17.2 RESOURCES

Our group did meet the budget by not spending more than $100 and keeping overall costs below $1,000. We spent $31.40 and overall costs were $600.00 the overall costs could be cut down because most of the costs are coming from including Jason's $500.00 laptop. To cut this cost down we could use a Raspberry Pi and a monitor which together probably would cost a maximum of $150.00 for the correct specifications which would bring our overall costs down to just over $200.00 see Appendix K for more information on final budget/ bill of materials. I personally spent money on and acquired the acrylic paint, paint brushes, and 3D printed the servo motor holders and dowels. I was reimbursed by my group and we split all costs evenly. On average I spent about 10-20 hours on this project every week see Appendix L for more information on weekly group hours.

This experience has allowed me to realize tracking and predicting elapsed time that a project will take is important especially when meeting deadlines. In the future I plan to track my time more closely and make sure that all contributors including myself are giving fair predictions for tasks and documenting fair amounts of time spent on tasks.

17.3 REFLECTIONS ON LEARNING

Lessons learned throughout this project have stemmed from the learning goals of this course. Specifically, working with a group to solve a problem, meeting deadlines and working quickly all while thinking critically. I never worked in a group for an engineering project so that was new for me. As a result of this project, I learned that things always don't work out as you first planned them to work out. An example of this is our design changed throughout the process due to eliminating and working around unfeasible features and trying to meet all the course and client requirements.

Throughout this project, I taught myself how to adapt to things not working out. An example of this is when I was rapid prototyping using SolidWorks to 3D print and construct our design. I faced challenges and made mistakes but I did not give up. I thought of creative ways to improvise and made it work. Notably, I 3D printed a second time making appropriate changes that would make the servo motor holders and dowels work better in our design. In addition, because I was having red vests cut the wood as best they could I needed to sand and make sides of wood as level as possible to mitigate wobbliness and instability in the design.

I definitely enhanced my SolidWorks, woodworking, and spatial reasoning skills in this project. Although woodworking skills may not be as useful in my career as a mechanical engineer, SolidWorks and spatial reasoning skills are definitely skills that I will rely heavily upon and will continue to enhance to benefit me in my future as a mechanical engineer.

17.4 RELFECTIONS ON WORKING AS A TEAM

Throughout project 1 I took the role as a project manager as I submitted our milestones, distributed work and ensured milestones got completed from start to finish. During my time as project manager during project 2 milestone 1 not much changed in our dynamic aside from one of our group members getting sick which delayed his ability to get his work done which also pushed back our group work from getting submitted. This project changed my team working skills because it has caused me to enhance and increase my inclusiveness and communication with group members. My leadership style was mainly distributing work for team members to complete and guiding members when questions arose. I believe I was easily managed and tried my best to get all of the things I was assigned to do done efficiently and effectively.

Challenges that our group overcame were being able to navigate through this project while being down one group member for majority of the project. Despite one group member contributing less and eventually losing that group member our team dynamic was strong and we distributed our work relatively evenly throughout the project. Specifically, Ajay did majority of the writing in memorandums, Jason did all of the coding, and I did most of the acquiring of materials, constructing and painting the project this dynamic worked and we were able to successfully complete and tend to all milestones and parts of the project.

In our team contract we laid out team dynamics we wanted which include respect, commitment, transparency, communication, & justice. The biggest assets to our team was our quick response times, being there for each other, the feedback received from classmates, and seeing aspects of their designs that could be adapted for use in our own exhibit. If I could go back to the beginning of the semester and start over I would have spent more time on team contract and used it as a reference in the future if a group member was not contributing as much as others.

Additionally, I wish I was more assertive and direct when it came to getting parts of the project completed. If we had more time implementing a leaderboard and music would be two very positive additions to our exhibit

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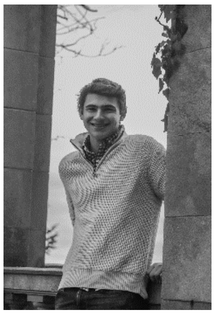
AUTHOR BIOGRAPHY – ANDREW HEDBERG



Andrew Hedberg was born in Hartford, Connecticut on June 24th, 2004. Andrew resided in Southington, Connecticut and moved to Old Lyme, Connecticut in 2017. Andrew graduated from Lyme-Old Lyme High School in Old Lyme, Connecticut and is currently a student at Northeastern University pursuing a Bachelor of Science degree in mechanical engineering.

He has gained an interest in robotics, biomedical devices, and performance testing of equipment. He is very well-accomplished for his age, having overcome multiple obstacles, having held multiple jobs and positions all that have led to him pursuing a Bachelor of Science degree in mechanical engineering. The biggest obstacle he faced was being diagnosed with a rare form of bone cancer called osteosarcoma at the age of 7 years old changing his life and altering his perspectives. This obstacle led him to his interest in biomedical devices because although he did not have to amputate his leg this was an option and for others amputation can be their only option. Biomedical devices like prosthetics allow for users to be able to walk or do activities they would otherwise be unable to do because of their amputation. Jobs that he has held include working as golf staff at a golf course called Black Hall Club in Old Lyme, Connecticut, being an N.U.in alumni ambassador, and resident assistant at Northeastern University.

Mr. Hedberg is a member of the American Society of Mechanical Engineers at Northeastern University, member of Northeastern Robotics, volunteer for Roxbury Robotics at Northeastern University, ambassador/ spokesperson for Dana Farber Cancer Institute, and an ambassador agent for Make It Better (MIB) Agents.

APPENDICES

APPENDIX A – TEAM CONTRACT

Northeastern University
College *of* Engineering

Full Cornerstone Memorandum

To: Brian O'Connell
From: Andrew Hedberg
Date: 01/22/2023
Subject: Team Contract for team Hydra, Wizards, or Dragons
CC: Jason Lu, Ajay Haridasse, and Jacob Rabold
Attachments: Contact Information (Attachment 1), Weekly Schedule (Attachment 2), Important Dates (Attachment 3)

This memo serves as the team contract for team Hydra. Its purpose is to establish a set of rules for our teamwork and interactions for our Spring 2022 Cornerstone projects. It covers how all members agree to take the following into consideration in our team dynamics: **respect, commitment, transparency, communication, & justice**. It also formally records team information, our preferred team names, and our goals for the semester, included in attachment 1. Calendars of our weekly responsibilities and a record of major events throughout the semester are also included in attachment 2 & 3.

Respect
Overall late work and late submissions will not be tolerated. Work should be shared an entire day (24 hours) in advance before the overall deadline so all of the work can be put together in a timely and reasonable manner. If someone violates these procedures, we will communicate with them and see what we can do in the future. If the issue is recurring then we will meet with Professor O'Connell to see what can be done.

Commitment
Our hours are flexible, and we can find times to meet. We will use text to communicate throughout the day every week. Our expectations for quality will be high quality and this quality will be assessed by the entire group and then the group will decide if the final project is good enough to be submitted. If someone violates these procedures, we will communicate with them and see what we can do in the future and if the issue is recurring then we will meet with Professor O'Connell to see what can be done.

Transparency

We should collaboratively make decisions. All information is shared with each other. We will be using google drive folder for shared documents. Meetings can be recorded, and meetings are open for discussion. Be transparent about issues and speak up. If we are transparent about issues/conflicts it can make everyone's lives easier when working and getting our assignments done and submitted on time. If someone feels excluded they should communicate that they are feeling excluded to the rest of the group and then the group as a whole can come to a solution on how the group member feeling excluded can not feel that way. If a solution can not be met we can ask Professor O'Connell for advice on how to solve the problem.

Communication

Our main communication technique will be through an iMessage text group chat. If you communicate that you will complete a task by a certain time on a certain day you need to be responsible for what you agree upon. You will be held accountable if you don't get your parts done. If this becomes a recurring issue Professor O'Connell will be notified. Making sure we take notes during meetings and recording everything and not ruling anyone's ideas out is also an important part of our communication.

Justice

We will define equitable contribution as almost equal distribution of time and effort put into the assignments. Our group will work to prevent conflict by communicating and being transparent about our issues, time commitments and what is going on in our separate lives. We understand we all have different responsibilities and obligations and can work to reallocate work if someone can't contribute as much as others at one specific time. If someone stops/doesn't contribute or isn't effectively contributing to the project the group member(s) will discuss this issue between themselves and with the respective group member(s) who are not contributing evenly. If we can't come to a solution and group member(s) continue to not contribute or contribute evenly then Professor O'Connell will be notified.

Summary

This memo serves as the team contract for team Hydra and records our team information, schedules, and agreements regarding our team dynamics. For further details on our discussions, please see our Design Notebook for notes on our discussions. For further details or inquiries, please contact us. Contact information available in Attachment 1.

Signed,

Team Member 1	Team Member 3
Andrew Hedberg	Ajay Haridasse
Team Member 2	Team Member 4
Jacob Rabold	Jason Lu

Attachment 1: Team Information

Contact Information

Name	Email	Phone	Preferred Contact
Team Member 1	hedberg.a@northeastern.edu	(860) 919-6880	Text
Team Member 2	rabold.j@northeastern.edu	(978) 223-7425	Text
Team Member 3	haridasse.a@northeastern.edu	(781) 771-0662	Text
Team Member 4	lu.jason2@northeastern.edu	(425) 240-1880	Text

Team names in preferred order:

1. Hydra
2. Wizards
3. Dragons

Project Manager Assignments for Project 1:
Milestone 1 (Andrew) – Problem Definition and Solution Generation
Milestone 2 (Jacob) – Decision Making and Implementation
Milestone 3(Ajay) – Testing and Evaluation
Milestone 4 (Jason) – Presentation

APPENDIX B - DESCISION ANALYSIS

After establishing group goals along with their respective ratings through a rank order chart, the group narrowed down which design was best based off of a KTDA chart. The highest scoring design was the Solar Powered Tug of War. This design scored the highest mainly due to its high scores in the two most heavily weighted categories: Educational and Interactive.

1. RANK ORDER CHART

	Educational	Interactive	Size/portability	Realistic	Easy to Build/set up	Collects data	Cost	Total
Educational	-	1	1	1	1	1	1	6
Interactive	0	-	1	1	1	1	1	5
Size/portability	0	0	-	1	1	1	0.5	3.5
Realistic	0	0	0	-	0.5	1	0	1.5
Easy to build/set up	0	0	0	0.5	-	1	0	1.5
Collects Data	0	0	0	0	0	-	0	0
Cost	0	0	0.5	1	1	1	-	3.5

Order of Importance:

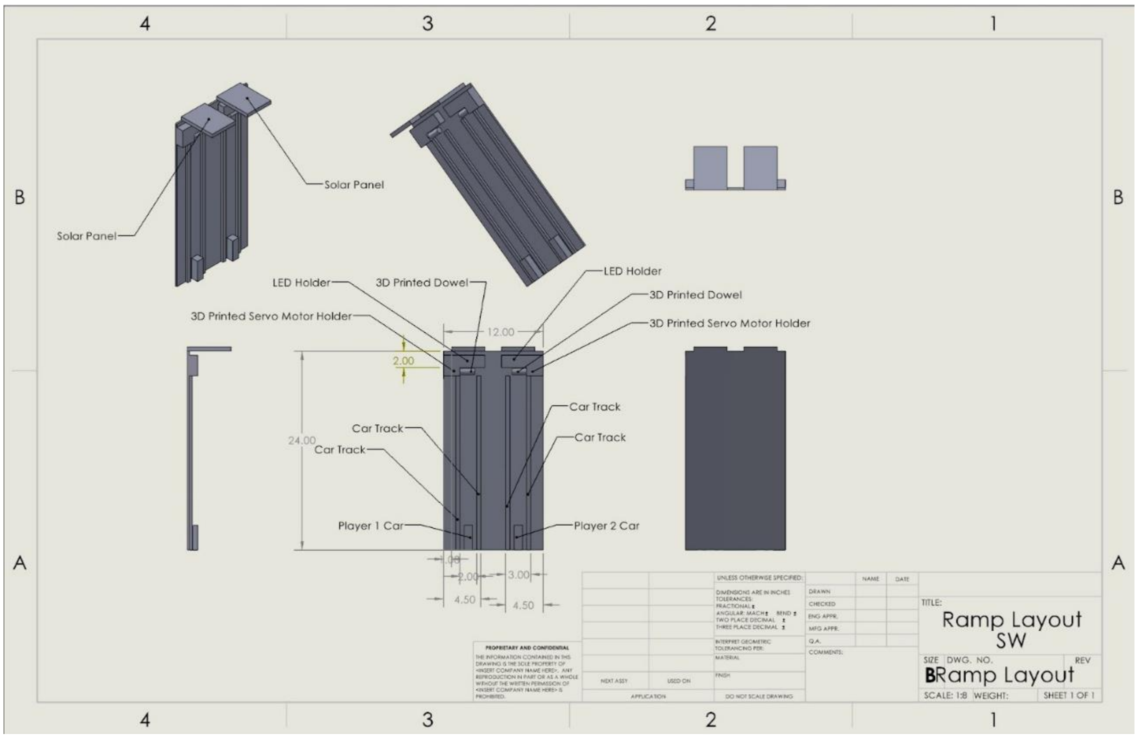
1. Educational
2. Interactive
3. Size/portability
   Cost
4. Realistic
   Easy to build/set up
5. Collects Data

2. Group Decision Matrix Ratings for Design Goals (KTDA Chart)

	Educational		Interactive		Size/portability		Cost		Realistic		Easy to Build		Collects Data		Total
Weights	6.5		5		3.5		3.5		1.5		1.5		1		
Geothermal Exhibit (Jason)	9.50	61.75	5.00	25.00	9.50	33.25	7.75	27.13	7.75	11.63	8.75	13.13	1.50	1.50	173.38
Tidal Exhibit (Jason)	8.75	56.88	8.75	43.75	8.00	28.00	7.00	24.50	7.75	11.63	8.75	13.13	1.50	1.50	179.38
Hydroelectric vs. Solar cars (Ajay)	7.75	50.38	5.50	27.50	7.13	24.94	6.00	21.00	5.75	8.63	5.38	8.06	4.25	4.25	144.75
Solar Tug of War (Ajay)	7.75	50.38	10.00	50.00	8.75	30.63	8.25	28.88	7.25	10.88	8.00	12.00	8.50	8.50	191.25
Windmill Exhibit (Andrew)	7.63	49.56	6.25	31.25	8.50	29.75	6.75	23.63	8.50	12.75	7.25	10.88	5.75	5.75	163.56
Hydroelectric power/water mill (Andrew)	7.75	50.38	5.75	28.75	7.50	26.25	6.88	24.06	8.50	12.75	5.75	8.63	4.50	4.50	155.31
Solar powered LCD display (Jacob)	8.25	53.63	5.75	28.75	9.50	33.25	9.00	31.50	7.50	11.25	8.75	13.13	7.00	7.00	178.50
Tilting solar power exhibit (Jacob)	8.25	53.63	7.25	36.25	9.5	33.25	8.00	28.00	7.75	11.63	4.75	7.13	8.25	8.25	175.50

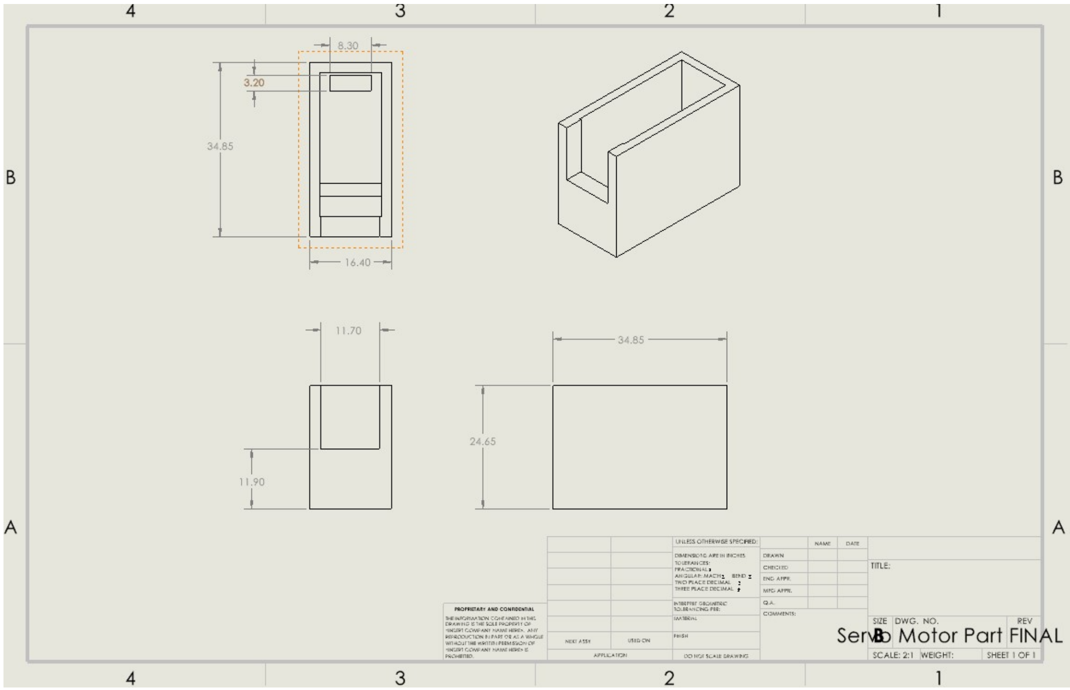
APPENDIX C - FINAL AUTOCAD/SOLIDWORKS DRAWINGS

Full Prototype Assembly:

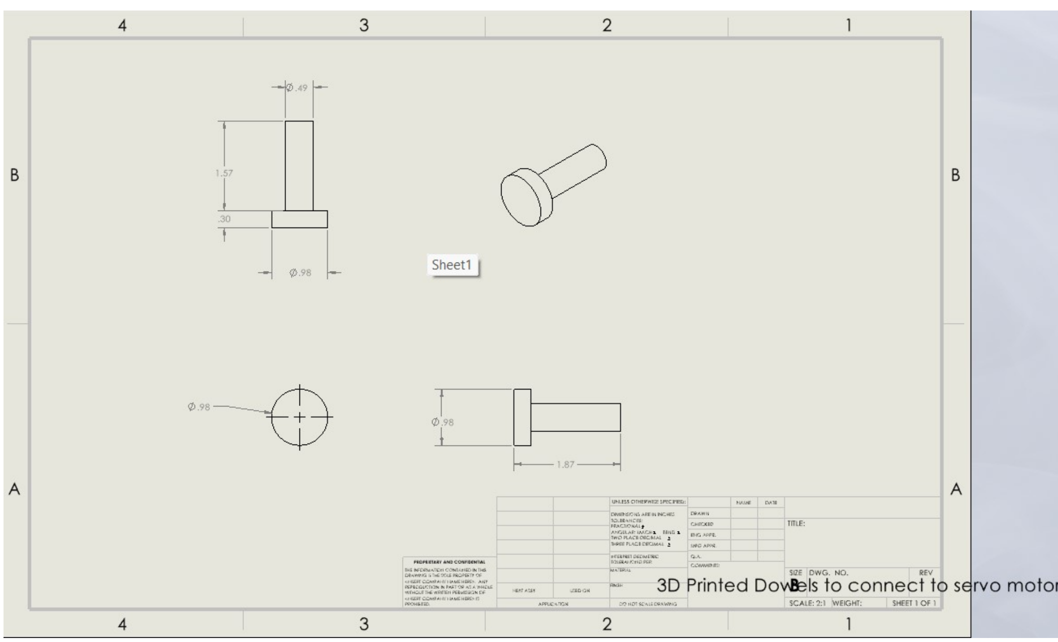


Educational Solar Panel Box/ Laptop Holder

3D Printed Servo Motor Holder



3D Printed Dowels



APPENDIX D – PRODUCT TESTING RESULTS

Overall, our exhibit performed well throughout the entirety of the expo despite a few minor things that we did not realize we would encounter as well as things that were out of our control. Issues we found that only occurred once was when the start button was pressed an additional time after the users were already prompted with true or false questions as well as the buttons having to be pressed very hard or multiple times for the computer to read due to how old the button was. Along with this, we found that in the case that a user does not get any of the questions right, the car was never able to cover their sides photoresistor to end and reset the game, which forced us to manually do so.

To analyze how well the users were learning, the group used the time of use by each set of users as well as what question the game ended on to analyze this. Since the cars reach the top of the ramp the more correct the users are throughout the game, we found that the shorter amount of time the game took to end meant the users were answering questions faster and more correctly, leading to the motors speeding up and ending the game faster. Overall, using a random sample of 10 of the 21 total games, the average time of play was 45.97 seconds with the average of the question ending being 3.73. Along with this sampling of data, we also found that when users came back to play again the time it took for the game to end was shorter, considering they already had seen the question set and knew the answers, showing they remembered from their previous attempt.

Aside from statistical data, we also recorded comments we received on our exhibit during and following completion of users participating in the exhibit. Users stated how they liked the aesthetics of the exhibit, commenting on both the presentation of the MATLAB application as well as the ramp and the car portion of the exhibit. We also received comments regarding the flow of the game, as they liked the idea of racing against someone as well as how clean the reset is with the cars being unwinded back to the bottom. The comments received were mainly positive which is a good and bad thing, as not getting any negative comments may be due to users not wanting to bluntly tell us.

Expo Data

Set of Users	Time of Use	Question game ended on	Comment Feedback (Unrelated to set of users)
1	59.12	5	“This game is fun!”
2	35.8	3	“The Matlab app was cute.”
3	45.91	4	“Very cool game simulating solar energy!”
4	72.2	5	“Had so much fun even played it again!”
5	52.78	4	"Really cute and impressive!"
6	45.43	4	"Pretty cool concept, I like it"
7	43.06	4	"That's sick!"
8	53.71	5	
9	51.25	4	
10	50.02	4	
11	43.75	3	
12	50.25	4	
13	47.8	3	
14	56.23	5	
15	39.3	3	
16	51.92	5	
17	42.49	4	
18	54.44	5	
19	36.87	3	
20	32.9	3	
21	40.43	3	
Rand Samp Avg.	45.97	3.73	
Total Avg.	47.9	3.95	

APPENDIX E – CODE USED IN PROJECT

```
classdef finalfinalcode < matlab.apps.AppBase

    % Properties that correspond to app components
    properties (Access = public)
        UIFigure  matlab.ui.Figure
        Label     matlab.ui.control.Label
        Label_2   matlab.ui.control.Label
        Image     matlab.ui.control.Image
    end


    properties (Access = private)
        %define variables
        RBrd
        s1
        s2
    end


    % Callbacks that handle component events
    methods (Access = private)

        % Code that executes after component creation
        function startupFcn(app)
            %display start screen
            app.Image.ImageSource = 'startpage.png';
            %set up arduino
            com = 'com3';
            app.RBrd = arduino(com,'uno', 'Libraries', {'Adafruit/NeoPixel',
'Servo'});
            pause(1);
            %set up LED
            led1 = addon(app.RBrd, 'Adafruit/NeoPixel', 'D11', 9,
'NeoPixelType', 'GRBW');
            led2 = addon(app.RBrd, 'Adafruit/NeoPixel', 'D12', 9,
'NeoPixelType', 'GRBW');
            pause(1);
            %set up servos and buttons
            app.s1 = servo(app.RBrd, 'D8');
            configurePin(app.RBrd, 'D2', 'pullup');
            configurePin(app.RBrd, 'D3', 'pullup');
            app.s2 = servo(app.RBrd, 'D9');
            configurePin(app.RBrd, 'D5', 'pullup');
            configurePin(app.RBrd, 'D6', 'pullup');
            %set servo speed to 0
            writePosition(app.s1, 0.5);
            writePosition(app.s2, 0.5);
```

```
configurePin(app.RBrd, 'D7', 'pullup');
pause(1);
%finish line
line = 1;
%set reset = no
reset = 0;
%set question = 1
question = 1;
%set win equal to no one
win = 0;
%start equal not started yet
start = 0;
%repeatedly check whether the start button has been pressed
while 1
    strtstp = readDigitalPin(app.RBrd, 'D7');
    %if start button pressed
    if strtstp == 0
        %display instructions screen
        app.Image.ImageSource = 'instructions.png';
        pause(3);
        %while the game has not started check to see if the
        %start button has been pressed
        while start == 0
            strtstp = readDigitalPin(app.RBrd, 'D7');
            %if start button pressed
            if strtstp == 0
                %set start equal to yes
                start = 1;
            end
        end
        %while the game is started
        while start == 1
            %if question value is equal to 1
            if question == 1
                %start spinning the servos very slowly and
                %light up the first LED for each player
                speed1 = 0.54;
                speed2 = 0.54;
                writeColor(led1, 1, [1,1,0,0]);
                writeColor(led2, 1, [1,1,0,0]);
                %set player 1 and 2 = unanswered
                player1 = 0;
                player2 = 0;
                %display question 1
                app.Image.ImageSource = '1.png';
                writePosition(app.s1, speed1);
                writePosition(app.s2, speed2);
                %while player 1 or player 2 = unanswered
                while player1 == 0 || player2 == 0
                    %check buttonstatus for each player
```

```
tb1 = readDigitalPin(app.RBrd, 'D2');
fb1 = readDigitalPin(app.RBrd, 'D3');
tb2 = readDigitalPin(app.RBrd, 'D5');
fb2 = readDigitalPin(app.RBrd, 'D6');
strtstp = readDigitalPin(app.RBrd, 'D7');
%check if any player has finished
finish1 = app.RBrd.readVoltage('A0');
finish2 = app.RBrd.readVoltage('A1');
%if player 1 presses false button and
%player 1 is unanswered
if fb1 == 0 && player1 == 0
    %increase servo speed
    speed1 = 0.56;
    writePosition(app.s1, speed1);
    writePosition(app.s2, speed2);
    %set player 1 = answered
    player1 = 1;
    %display that they answered correctly
    app.Label_2.Text = 'Correct!';
    %light up another LED for player 1
    writeColor(led1, 1:2, [1,1,0,0]);
%elseif player 1 presses true button and
%player 1 is unanswered
elseif tb1 == 0 && player1 == 0
    %dont change the servo speed
    writePosition(app.s1, speed1);
    writePosition(app.s2, speed2);
    %set player 1 = answered
    player1 = 1;
    %display that they answered wrong
    app.Label_2.Text = 'Wrong!';
%elseif player 2 presses false button and
%player 2 is unanswered
elseif fb2 == 0 && player2 == 0
    %increase servo speed
    speed2 = 0.56;
    writePosition(app.s1, speed1);
    writePosition(app.s2, speed2);
    %set player 2 = answered
    player2 = 1;
    %display that they answered correctly
    app.Label.Text = 'Correct!';
    %light up another LED for player 2
    writeColor(led2, 1:2, [1,1,0,0]);
%elseif plyer 2 presses true button and
%player 2 is unanswered
elseif tb2 == 0 && player2 == 0
    %dont change servo speed
    writePosition(app.s1, speed1);
    writePosition(app.s2, speed2);
```

```
                %set player 2 = answered
                player2 = 1;
                %disply that they answered wrong
                app.Label.Text = 'Wrong!';
            %if player 1 passes the finish line
            elseif finish1 < line
                %stop player 1 servo
                writePosition(app.s1, 0.5);
                %set both players to answered
                player1 = 1;
                player2 = 1;
                %indicate that the game if to be reset
                reset = 1;
                %indicate that player 1 has won
                win = 1;
            %else if player 2 passes the finish line
            elseif finish2 < line
                %stop player 2 servo
                writePosition(app.s2, 0.5);
                %set both players to answered
                player1 = 1;
                player2 = 1;
                %indicate that the game has to be reset
                reset = 1;
                %indicate that player 2 has won
                win = 2;
            %end
            end
            %if the game has to be reset
            if reset == 1
                %set question = 0 to indicate reset and
                %game end
                question = 0;
            %else
            else
                %increase question by 1
                question = 2;
            %end
            end
        %end
        end
        pause(1);
        app.Label_2.Text = ' ';
        app.Label.Text = '';

    %if question value is 2
    elseif question == 2
        %set player 1 and 2 = unanswered
        player1 = 0;
        player2 = 0;
```

```
%display question 2
app.Image.ImageSource = '2.png';
writePosition(app.s1, speed1);
writePosition(app.s2, speed2);
%while player 1 or player 2 = unanswered
while player1 == 0 || player2 == 0
    %check buttonstatus for each player
    tb1 = readDigitalPin(app.RBrd, 'D2');
    fb1 = readDigitalPin(app.RBrd, 'D3');
    tb2 = readDigitalPin(app.RBrd, 'D5');
    fb2 = readDigitalPin(app.RBrd, 'D6');
    %check if any player has finished
    finish1 = app.RBrd.readVoltage('A0');
    finish2 = app.RBrd.readVoltage('A1');
    %if player 1 presses true button and player
    % 1 is unanswered
    if tb1 == 0 && player1 == 0
        %increase servo speed
        speed1 = 0.58;
        writePosition(app.s1, speed1);
        writePosition(app.s2, speed2);
        %set player 1 = answered
        player1 = 1;
        %dislpay that player 1 answered
        %correctly
        app.Label_2.Text = 'Correct!';
        %light up another LED for player 1
        writeColor(led1, 1:3, [1,1,0,0]);
    %elseif player 1 presses false button and
    %player 1 is unanswered
    elseif fb1 == 0 && player1 == 0
        %dont change servo speed
        writePosition(app.s1, speed1);
        writePosition(app.s2, speed2);
        %set player 1 = answered
        player1 = 1;
        %display that they got the question
        %wrong
        app.Label_2.Text = 'Wrong!';
    %elseif player 2 presses true button and
    %is unanswered
    elseif tb2 == 0 && player2 == 0
        %increase servo speed
        speed2 = 0.57;
        writePosition(app.s1, speed1);
        writePosition(app.s2, speed2);
        %set player 2 = answered
        player2 = 1;
        %display that they answered correct
        app.Label.Text = 'Correct!';
```

```
        %light another LED for player 2
        writeColor(led2, 1:3, [1,1,0,0]);
    %elseif plyer 2 presses false button and
    %hasnt answered the question
    elseif fb2 == 0 && player2 == 0
        %dont change servo speed
        writePosition(app.s1, speed1);
        writePosition(app.s2, speed2);
        %set player 2 = answered
        player2 = 1;
        %display that they answered wrong
        app.Label.Text = 'Wrong!';
    %if player 1 passes the finish line
    elseif finish1 < line
        %stop player 1 servo
        writePosition(app.s1, 0.5);
        %set both players to answered
        player1 = 1;
        player2 = 1;
        %indicate that the game if to be reset
        reset = 1;
        %indicate that player 1 has won
        win = 1;
    %else if player 2 passes the finish line
    elseif finish2 < line
        %stop player 2 servo
        writePosition(app.s2, 0.5);
        %set both players to answered
        player1 = 1;
        player2 = 1;
        %indicate that the game has to be reset
        reset = 1;
        %indicate that player 2 has won
        win = 2;
    %end
    end
    %if the game has to be reset
    if reset == 1
        %set question = 0 to indicate reset and
        %game end
        question = 0;
    %else
    else
        %increase question by 1
        question = 3;
    %end
    end
%end
end
pause(1);
```

```
        app.Label_2.Text = '';
        app.Label.Text = '';

    %else if the question value is = 3
    elseif question == 3
        %set player 1 and 2 = unanswered
        player1 = 0;
        player2 = 0;
        %display question 3
        app.Image.ImageSource = '3.png';
        writePosition(app.s1, speed1);
        writePosition(app.s2, speed2);
        %while player 1 or player 2 = unanswered
        while player1 == 0 || player2 == 0
            %check buttonstatus for each player
            tb1 = readDigitalPin(app.RBrd, 'D2');
            fb1 = readDigitalPin(app.RBrd, 'D3');
            tb2 = readDigitalPin(app.RBrd, 'D5');
            fb2 = readDigitalPin(app.RBrd, 'D6');
            %check if any player has finished
            finish1 = app.RBrd.readVoltage('A0');
            finish2 = app.RBrd.readVoltage('A1');
            %if player 1 presses false button and hasnt
            %answered
            if fb1 == 0 && player1 == 0
                %increase servo speed for player 1
                speed1 = 0.59;
                writePosition(app.s1, speed1);
                writePosition(app.s2, speed2);
                %set player 1 = answered
                player1 = 1;
                %display that they answered correct
                app.Label_2.Text = 'Correct!';
                %light up another LED for player 1
                writeColor(led1, 1:4, [1,1,0,0]);
            %elseif player 1 presses true button and
            %hasnt answered
            elseif tb1 == 0 && player1 == 0
                %dont change servo speed
                writePosition(app.s1, speed1);
                writePosition(app.s2, speed2);
                %set player 1 = answered
                player1 = 1;
                %display that player 1 answered wrong
                app.Label_2.Text = 'Wrong!';
            %elseif player 2 presses false button and
            %hasnt answered
            elseif fb2 == 0 && player2 == 0
                %increase servo speed for player 2
                speed2 = 0.585;
```

```
    writePosition(app.s1, speed1);
    writePosition(app.s2, speed2);
    %set player 2 = answered
    player2 = 1;
    %display that player 2 answered correct
    app.Label.Text = 'Correct!';
    %light up another LED for player 2
    writeColor(led2, 1:4, [1,1,0,0]);
%elseif plyer 2 presses true button and
%hasnt answered
elseif tb2 == 0 && player2 == 0
    %dont change servo speed
    writePosition(app.s1, speed1);
    writePosition(app.s2, speed2);
    %set player 2 = answered
    player2 = 1;
    %display that player 2 answered wrong
    app.Label.Text = 'Wrong!';
%if player 1 passes the finish line
elseif finish1 < line
    %stop player 1 servo
    writePosition(app.s1, 0.5);
    %set both players to answered
    player1 = 1;
    player2 = 1;
    %indicate that the game if to be reset
    reset = 1;
    %indicate that player 1 has won
    win = 1;
%else if player 2 passes the finish line
elseif finish2 < line
    %stop player 2 servo
    writePosition(app.s2, 0.5);
    %set both players to answered
    player1 = 1;
    player2 = 1;
    %indicate that the game has to be reset
    reset = 1;
    %indicate that player 2 has won
    win = 2;
%end
end
%if the game has to be reset
if reset == 1
    %set question = 0 to indicate reset and
    %game end
    question = 0;
%else
else
    %increase question by 1
```

```
                question = 4;
            %end
            end
        %end
        end
        pause(1);
        app.Label_2.Text = '';
        app.Label.Text = '';

    %else if question value is = 4
    elseif question == 4
        %set player 1 and 2 = unanswered
        player1 = 0;
        player2 = 0;
        %display question 4
        app.Image.ImageSource = '4.png';
        writePosition(app.s1, speed1);
        writePosition(app.s2, speed2);
        %while player 1 or player 2 = unanswered
        while player1 == 0 || player2 == 0
            %check buttonstatus for each player
            tb1 = readDigitalPin(app.RBrd, 'D2');
            fb1 = readDigitalPin(app.RBrd, 'D3');
            tb2 = readDigitalPin(app.RBrd, 'D5');
            fb2 = readDigitalPin(app.RBrd, 'D6');
            %check if any player has finished
            finish1 = app.RBrd.readVoltage('A0');
            finish2 = app.RBrd.readVoltage('A1');
            %if player 1 presses false button and
            %hasnt answered the question
            if fb1 == 0 && player1 == 0
                %increase player 1 servo speed
                speed1 = 0.595;
                writePosition(app.s1, speed1);
                writePosition(app.s2, speed2);
                %set player 1 = answered
                player1 = 1;
                %display that player 1 answered correct
                app.Label_2.Text = 'Correct!';
                %light up another LED for player 1
                writeColor(led1, 1:5, [1,1,0,0]);
            %elseif player 1 presses true button
            elseif tb1 == 0 && player1 == 0
                %dont change servo speed
                writePosition(app.s1, speed1);
                writePosition(app.s2, speed2);
                %set player 1 = answered
                player1 = 1;
                %display that player 1 answered wrong
                app.Label_2.Text = 'Wrong!';
```

```
%elseif player 2 presses false button and
%hasnt answered
elseif fb2 == 0 && player2 == 0
    %increase servo speed for player 2
    speed2 = 0.59;
    writePosition(app.s1, speed1);
    writePosition(app.s2, speed2);
    %set player 2 = answered
    player2 = 1;
    %display that player 2 answered correct
    app.Label.Text = 'Correct!';
    %light up another LED for player 2
    writeColor(led2, 1:5, [1,1,0,0]);
%elseif plyer 2 presses false button and
%hasnt answered
elseif tb2 == 0 && player2 == 0
    %dont change servo speed
    writePosition(app.s1, speed1);
    writePosition(app.s2, speed2);
    %set player 2 = answered
    player2 = 1;
    %display that player 2 answered wrong
    app.Label.Text = 'Wrong!';
%if player 1 passes the finish line
elseif finish1 < line
    %stop player 1 servo
    writePosition(app.s1, 0.5);
    %set both players to answered
    player1 = 1;
    player2 = 1;
    %indicate that the game if to be reset
    reset = 1;
    %indicate that player 1 has won
    win = 1;
%else if player 2 passes the finish line
elseif finish2 < line
    %stop player 2 servo
    writePosition(app.s2, 0.5);
    %set both players to answered
    player1 = 1;
    player2 = 1;
    %indicate that the game has to be reset
    reset = 1;
    %indicate that player 2 has won
    win = 2;
%end
end
%if the game has to be reset
if reset == 1
    %set question = 0 to indicate reset and
```

```
                %game end
                question = 0;
            %else
            else
                %increase question by 1
                question = 5;
            %end
            end
        %end
        end
        pause(1);
        app.Label_2.Text = '';
        app.Label.Text = '';

    %elseif question value  = 5
    elseif question == 5
        %set player 1 and 2 = unanswered
        player1 = 0;
        player2 = 0;
        %display question 5
        app.Image.ImageSource = '5.png';
        writePosition(app.s1, speed1);
        writePosition(app.s2, speed2);
        %while player 1 or player 2 = unanswered
        while player1 == 0 || player2 == 0
            %check buttonstatus for each player
            tb1 = readDigitalPin(app.RBrd, 'D2');
            fb1 = readDigitalPin(app.RBrd, 'D3');
            tb2 = readDigitalPin(app.RBrd, 'D5');
            fb2 = readDigitalPin(app.RBrd, 'D6');
            %check if any player has finished
            finish1 = app.RBrd.readVoltage('A0');
            finish2 = app.RBrd.readVoltage('A1');
            %if player 1 presses true button and hasnt
            %answered
            if tb1 == 0 && player1 == 0
                %increase servo speed for player 1
                speed1 = 0.6;
                writePosition(app.s1, speed1);
                writePosition(app.s2, speed2);
                %set player 1 = answered
                player1 = 1;
                %display that player 1 answered correct
                app.Label_2.Text = 'Correct!';
                %light up another LED for player 1
                writeColor(led1, 1:6, [1,1,0,0]);
            %elseif player 1 presses false button and
            %hasnt answered
            elseif fb1 == 0 && player1 == 0
                %dont change servo speed
```

```
        writePosition(app.s1, speed1);
        writePosition(app.s2, speed2);
        %set player 1 = answered
        player1 = 1;
        %display that player 1 answered wrong
        app.Label_2.Text = 'Wrong!';
    %elseif player 2 presses true button and
    %hasnt answered
    elseif tb2 == 0 && player2 == 0
        %increase servo speed for player 2
        speed2 = 0.6;
        writePosition(app.s1, speed1);
        writePosition(app.s2, speed2);
        %set player 2 = answered
        player2 = 1;
        %display that player 2 answered correct
        app.Label.Text = 'Correct!';
        %light up another LED for player 2
        writeColor(led2, 1:6, [1,1,0,0]);
    %elseif plyer 2 presses false button and
    %hasnt answered
    elseif fb2 == 0 && player2 == 0
        %dont change servo speed
        writePosition(app.s1, speed1);
        writePosition(app.s2, speed2);
        %set player 2 = answered
        player2 = 1;
        %display that player 2 answered wrong
        app.Label.Text = 'Wrong!';
    %if player 1 passes the finish line
    elseif finish1 < line
        %stop player 1 servo
        writePosition(app.s1, 0.5);
        %set both players to answered
        player1 = 1;
        player2 = 1;
        %indicate that the game if to be reset
        reset = 1;
        %indicate that player 1 has won
        win = 1;
    %else if player 2 passes the finish line
    elseif finish2 < line
        %stop player 2 servo
        writePosition(app.s2, 0.5);
        %set both players to answered
        player1 = 1;
        player2 = 1;
        %indicate that the game has to be reset
        reset = 1;
        %indicate that player 2 has won
```

```
                win = 2;
            end
            %indicate the end of the game and to reset
            question = 0;
        %end
        end
        pause(1);
        app.Label_2.Text = '';
        app.Label.Text = '';

    %else if question value is = 0
    elseif question == 0
        %if player 1 won
        if win == 1
            %display player 1 win screen
            app.Image.ImageSource = 'p1.png';
            finish2 = app.RBrd.readVoltage('A1');
            %while player 2 hasnt crossed finish line
            while finish2 > line
                %check if player 2 has crossed finish
                finish2 = app.RBrd.readVoltage('A1');
                %keep player 2 servo spinning
                writePosition(app.s2, speed2);
            end
            %stop player 2 servo
            writePosition(app.s2, 0.5);
            %set speed of rewind
            rewind = 0.3;
            tic;
            %rewind the cars for 3.5 secs
            while toc < 3.5
                %rewind cars
                writePosition(app.s1, rewind);
                writePosition(app.s2, rewind);
            %end
            end
        %else if player 2 won
        elseif win == 2
            %display player 2 win screen
            app.Image.ImageSource = 'p2.png';
            finish1 = app.RBrd.readVoltage('A0');
            %while player 1 hasnt crossed finish line
            while finish1 > line
                %check if player 1 has finished
                finish1 = app.RBrd.readVoltage('A0');
                %keep player 1 servo spinning
                writePosition(app.s1, speed1);
            end
            %stop player 1 servo
            writePosition(app.s1, 0.5);
```

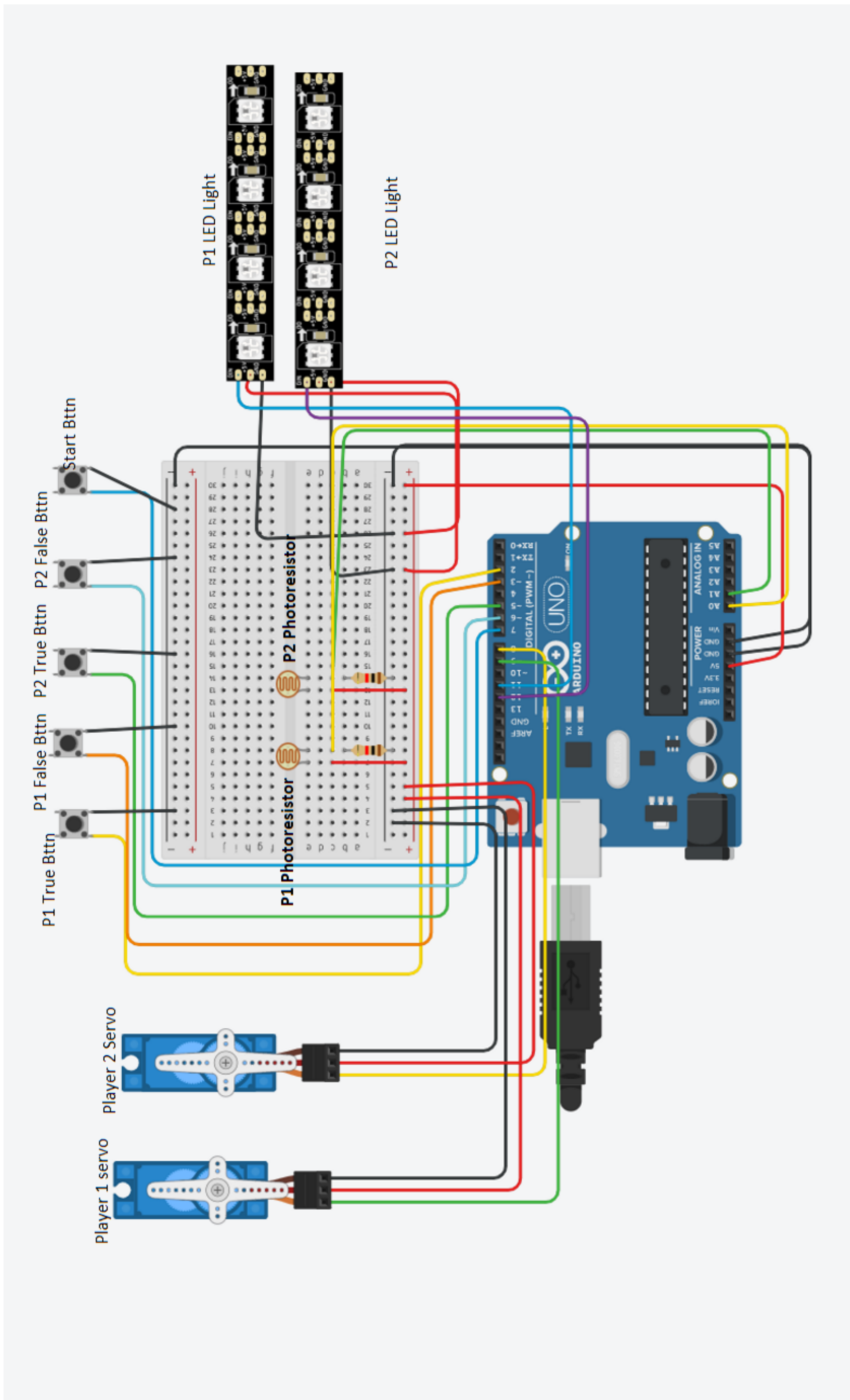
```
        %set rewind speed
        rewind = 0.3;
        tic;
        %rewind for 3.5 secs
        while toc < 3.5
            %rewind cars
            writePosition(app.s1, rewind);
            writePosition(app.s2, rewind);
        %end
        end
    %elseif no one has won yet
    elseif win == 0
        %both servos keep spinning
        writePosition(app.s1, speed1);
        writePosition(app.s1, speed2);
        %while no one has won yet
        while win == 0
            %check if either player has finished
            finish1 = app.RBrd.readVoltage('A0');
            finish2 = app.RBrd.readVoltage('A1');
            %if player 1 crosses finish line first
            if finish1 < line
                %indicated player 1 win
                win = 1;
                %stop player 1 servo
                writePosition(app.s1, 0.5);
            %if player 2 crosses finish line first
            elseif finish2 < line
                %indicated player 2 win
                win = 2;
                %stop player 2 servo
                writePosition(app.s2, 0.5);
            end
        end
        %if player 1 win
        if win == 1
            %display player 1 win screen
            app.Image.ImageSource = 'p1.png';
            finish2 = app.RBrd.readVoltage('A1');
            %while player 2 hasnt finished
            while finish2 > line
                %check if player 2 crossed finish
                finish2 = app.RBrd.readVoltage('A1');
                %keep player 2 servo spinning
                writePosition(app.s2, speed2);
            end
            %stop player 2 servo
            writePosition(app.s2, 0.5);
            %set rewind speed
            rewind = 0.3;
```

```
        tic;
        %rewind for 3.5 secs
        while toc < 3.5
            %rewind cars
            writePosition(app.s1, rewind);
            writePosition(app.s2, rewind);
        %end
        end
    %elseif player 2 win
    elseif win == 2
        %display player 2 win screen
        app.Image.ImageSource = 'p2.png';
        finish1 = app.RBrd.readVoltage('A0');
        %while player 1 hast finished
        while finish1 > line
            %check if player 1 crossed finish
            finish1 = app.RBrd.readVoltage('A0');
            %keep player 1 servo spinning
            writePosition(app.s1, speed1);
        end
        %stop player 1 servo
        writePosition(app.s1, 0.5);
        %set rewind speed
        rewind = 0.3;
        tic;
        %rewind for 3.5 secs
        while toc < 3.5
            %rewind cars
            writePosition(app.s1, rewind);
            writePosition(app.s2, rewind);
        %end
        end
    %end
    end
%end
end
pause(2);
%display start screen again
app.Image.ImageSource = 'startpage.png';
%indicate no player has won
win = 0;
%turn off all LEDs
writeColor(led1, 1:6, [0,0,0,0]);
writeColor(led2, 1:6, [0,0,0,0]);
%stop both servos
writePosition(app.s1, 0.5);
writePosition(app.s2, 0.5);
%reset question value
question = 1;
%indicate no reset needed
```

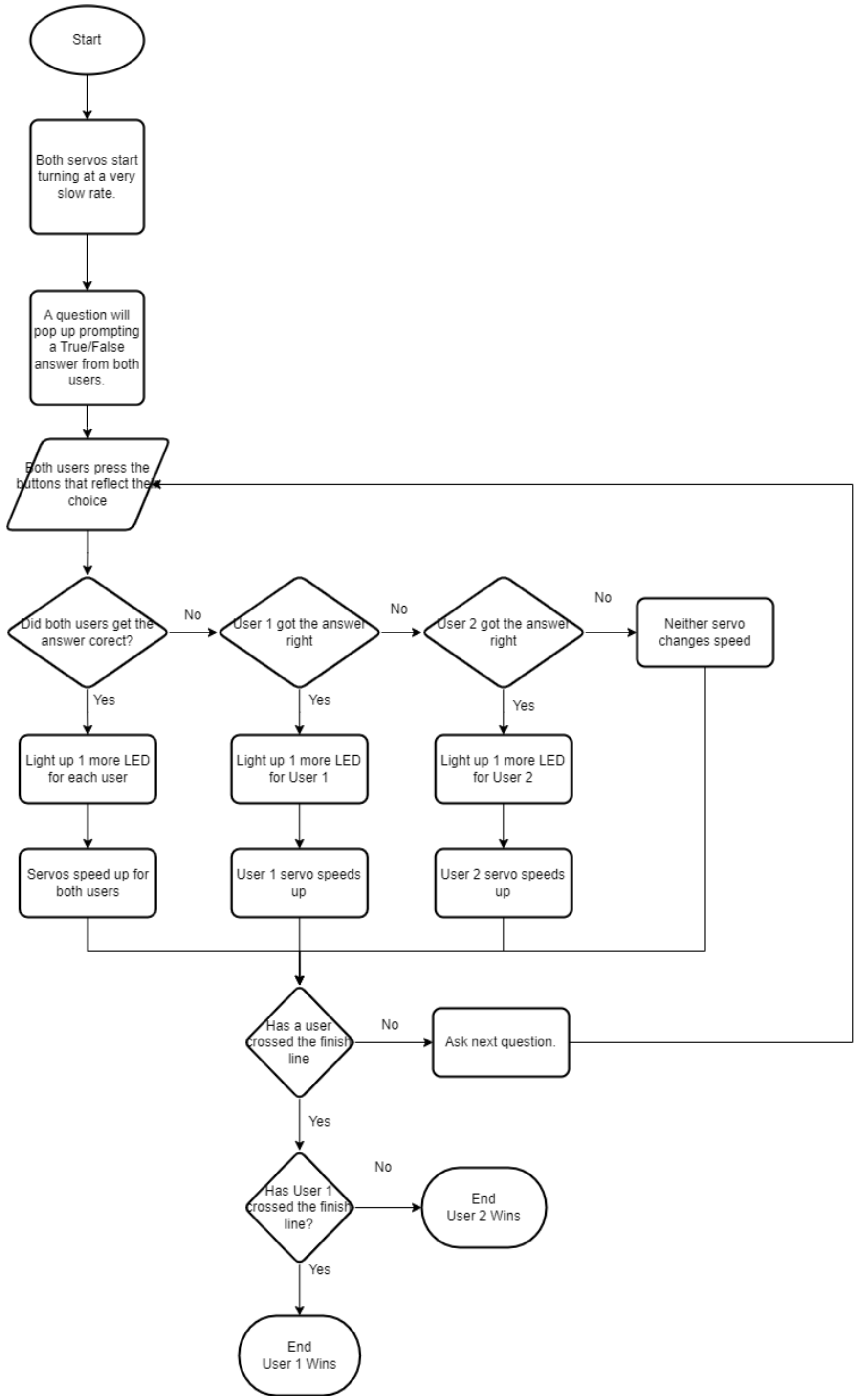
```
                        reset = 0;
                        %reset value indicating start of game
                        start = 0;
                    %end
                    end
                %end
                end
            %end
            end
        %end
        end
    end
end

% Component initialization
methods (Access = private)

    % Create UIFigure and components
    function createComponents(app)

        % Get the file path for locating images
        pathToMLAPP = fileparts(mfilename('fullpath'));

        % Create UIFigure and hide until all components are created
        app.UIFigure = uifigure('Visible', 'off');
        app.UIFigure.Position = [100 100 1059 610];
        app.UIFigure.Name = 'MATLAB App';

        % Create Image
        app.Image = uiimage(app.UIFigure);
        app.Image.ScaleMethod = 'fill';
        app.Image.Position = [1 0 1057 611];
        app.Image.ImageSource = fullfile(pathToMLAPP, 'startpage.png');

        % Create Label_2
        app.Label_2 = uilabel(app.UIFigure);
        app.Label_2.FontSize = 24;
        app.Label_2.FontWeight = 'bold';
        app.Label_2.Position = [485 164 151 31];
        app.Label_2.Text = '';

        % Create Label
        app.Label = uilabel(app.UIFigure);
        app.Label.FontSize = 24;
        app.Label.Position = [865 164 169 31];
        app.Label.Text = '';

        % Show the figure after all components are created
        app.UIFigure.Visible = 'on';
    end
```

```
    end

    % App creation and deletion
    methods (Access = public)

        % Construct app
        function app = finalfinalcode

            % Create UIFigure and components
            createComponents(app)

            % Register the app with App Designer
            registerApp(app, app.UIFigure)

            % Execute the startup function
            runStartupFcn(app, @startupFcn)

            if nargout == 0
                clear app
            end
        end

        % Code that executes before app deletion
        function delete(app)

            % Delete UIFigure when app is deleted
            delete(app.UIFigure)
        end
    end
end
```

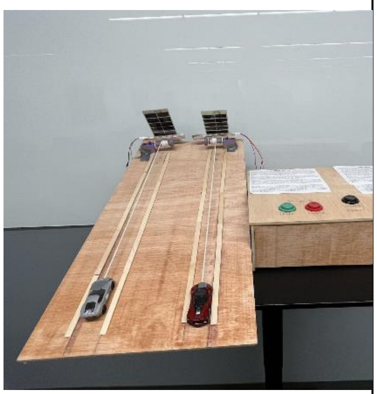
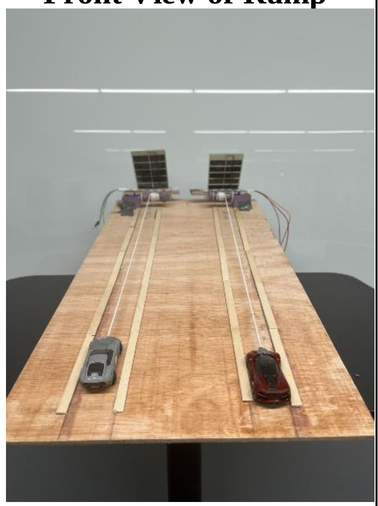
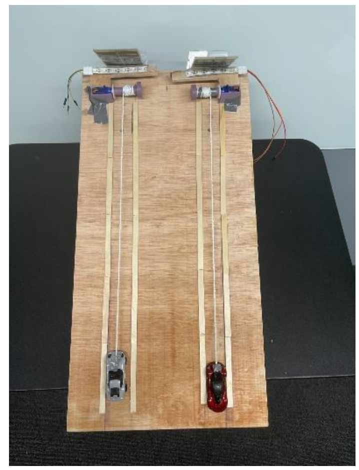
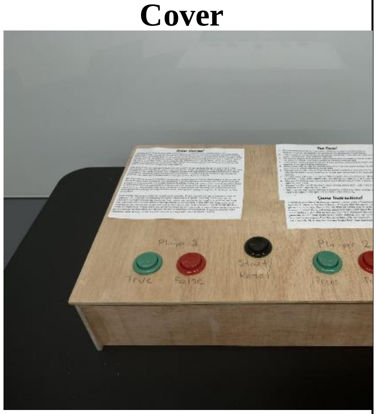
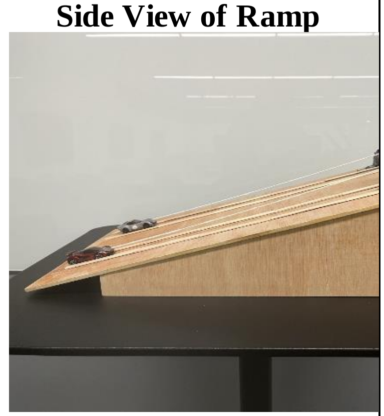
APPENDIX F – WIRE DIAGRAMS FOR SPARKFUN BOARDS

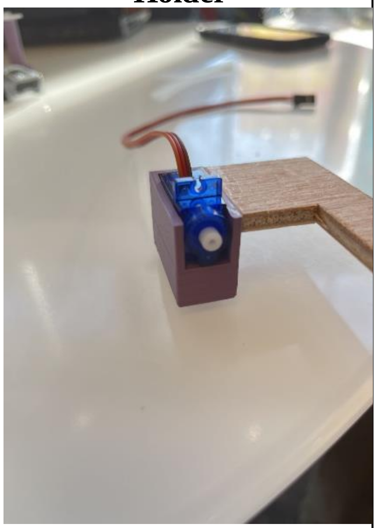


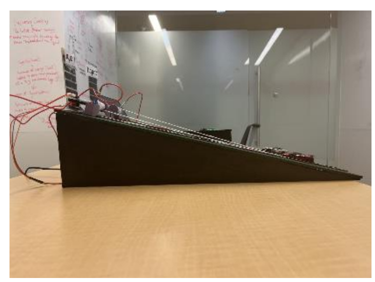
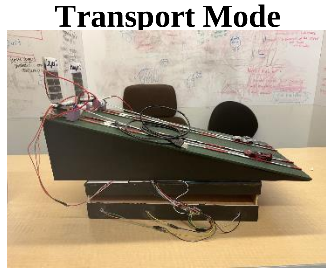
APPENDIX G – USER INTACTION FLOWCHART

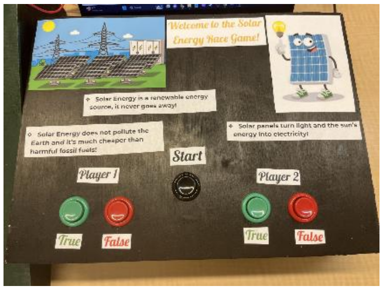
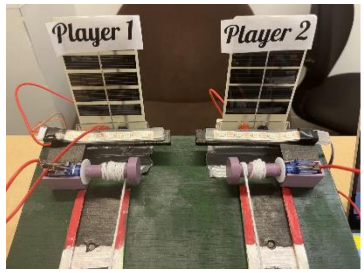
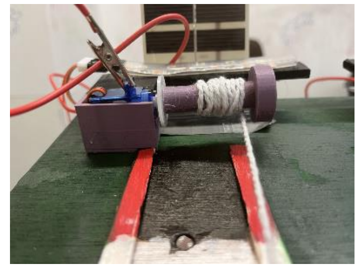
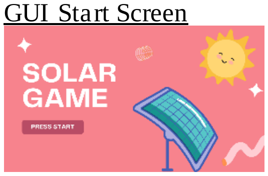


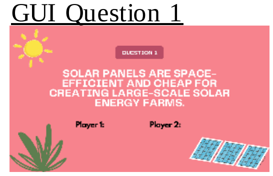
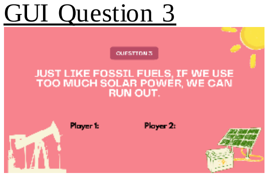
APPENDIX H – PHOTO LOG

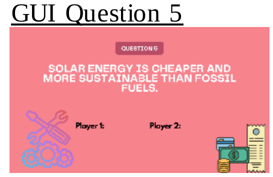
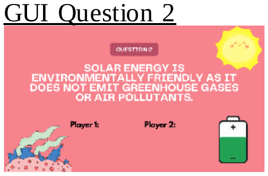
Milestone 5 90% Complete Prototype Photo Log		
Front View of Full Prototype 	**Front View of Ramp** 	**Top View of Ramp** 
Front View of Laptop Cover 	**Side View of Laptop Cover** 	**Side View of Ramp** 

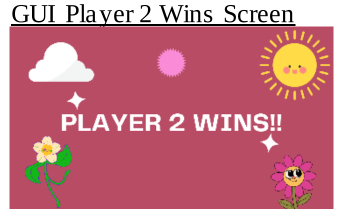
3D Printed Servo Motor Holder, and Wood LED Holder	3D Printed Dowel and Attachment	3D Printed Servo Holder and Wood LED Holder
		

Milestone 6 Complete Prototype Photo Log		
1. Front View of Exhibit	2. Top View of Exhibit	3. Left View of Exhibit
		
4. Right View of Exhibit	5. Exhibit in Transport Mode	6. Exhibit in Transport Mode in Bag
		

<table>
<tr>
<td>7. Top View of Educational Solar Panel Box and Interactive Buttons

</td>
<td>8. Servo Motors, 3-D printed holders and dowels, Solar Panels, and LEDs

</td>
<td>9. Servo Motor, 3D Printed Servo Motor Holder and Dowel and Wood, and Photoresistor Hole
</td>
</tr>
<tr>
<td><u>GUI Start Screen</u>

</td>
<td><u>GUI Game Instructions</u>

</td>
<td><u>GUI Question 1</u>

</td>
</tr>
<tr>
<td><u>GUI Question 3</u>

</td>
<td><u>GUI Question 4</u>

</td>
<td><u>GUI Question 5</u>

</td>
</tr>
<tr>
<td><u>GUI Question 2</u>

</td>
<td><u>GUI Player 1 Wins Screen</u>

</td>
<td><u>GUI Player 2 Wins Screen</u>

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APPENDIX I – EVALUATION PLAN CHART AND SURVEY RESULTS

2.1 EVALUATION PLAN CHART

Criteria	Data	Reasoning	Method	Analysis
Educational - keyboard cover surface (information and instructions)	How much the users learned from the information provided	Determines how much the keyboard cover teaches the user	User survey with 1-10 scale (1 being worst, 10 being best)	Survey results, the more the user learns, the more successful the exhibit is
Educational - true/false questions	How much the users learned from the true/false questions	Determines how much the true/false teaches the user	User survey with 1-10 scale (1 being worst, 10 being best)	Survey results, the more the user learns, the more successful the exhibit is
Educational - LEDs and fake solar panel	How much the users learned from the LED's lighting up near the fake solar panels	Determines how much the LED - solar panels teaches the user	User survey with 1-10 scale (1 being worst, 10 being best)	Survey results, the more the user learns, the more successful the exhibit is
Interest/Fun - true/false questions	How interesting/fun the users found the true/false questions	Determines how interesting the questions are to the user	User survey with 1-10 scale (1 being worst, 10 being best)	Survey results, the more fun the user has, the more successful the exhibit is
Interest/Fun - User vs. User car going up ramp + LEDs lighting up	How interesting/fun the users found the game of cars going up the ramp was	Determines how interesting the game aspect is to the user	User survey with 1-10 scale (1 being worst, 10 being best)	Survey results, the more fun the user has the more successful the exhibit is
Interactivity - entire exhibit	How involved did the user feel while at the exhibit	Determines how interactive the exhibit is for the user	User survey with 1-10 scale (1 being worst, 10 being best)	Survey results, the more interactivity / involved the user feels, the more successful the exhibit is
Clear/Understandable - keyboard cover surface	How clear/understandable the information provided and instructions were	Determines how easily the user is able to process the	User survey with 1-10 scale (1 being worst, 10 being best)	Survey results, the more understandable the informational text is, the more

		information from the cover		successful the exhibit is
Clear/Understandable - user interface	How clear/understandable the user interface is	Determines how easily the user is able to the process the information from the user interface	User survey with 1-10 scale (1 being worst, 10 being best)	Survey results, the more understandable and easier to read the user interface is, the more successful the exhibit is
Clear/Understandable - true/false questions	How clear/understandable the user interface is	Determines how easily the user is able to process the information from the questions	User survey with 1-10 scale (1 being worst, 10 being best)	Survey results, the more understandable and clear the true/false questions are, the more successful the exhibit is
Aesthetic/Cleanliness - entire exhibit	How nice/attractive the exhibit looks and how well the wires are hidden	Determines how organized and clean the exhibit looks	User survey with 1-10 scale (1 being worst, 10 being best)	Survey results, the better the exhibit looks and the better the wiring is hidden, the more successful the exhibit is
Function/errors	How well the exhibit flows or how many errors / times needed to be fixed	Determines how well the exhibit runs	Counter of the amount of errors occurred during exhibit presentation to public / User survey with 1-10 scale (1 being worst, 10 being best)	Observing flow, the smoother the exhibit flows and the less amount of times needed to fix, the more successful the exhibit is
Durability	How durable and how long the exhibit is able to withstand multiple uses	Determines how long the exhibit will be able to last without being fixed	Group observation	Observing wear and tear of project, the more durable and able the project is to have multiple users go through it, the more successful the exhibit is

Evaluation Survey

https://docs.google.com/forms/d/e/1FAIpQLSdLsVzFESOFCB5A7gYtBHDoMyaj21eF7AEE9yVv5NFbfhHTpQ/viewform?usp=sf_link

Evaluation Survey Results
https://docs.google.com/spreadsheets/d/1D0crowNwAu7XUsDlLOl8MHZfz2cVBKZMoRD2xMI4y_g/edit#gid=896622488

APPENDIX J – FINAL GANTT CHART

P2-Milestone 1	**PM 1**	**2/22**	**3/4**		**100%**
Initial Group Meeting	All	2/21	2/21	2hr	100%
Memorandum (Research Summary)	Jason Lu	2/21	2/23	3hr	100%
Memorandum (Problem Statement)	Ajay Haridasse	2/21	2/23	3hr	100%
Memorandum (Resources, Summary, and Works Cited)	All	2/22	2/23	2hr	100%
Attachment 1: Individual Background Research	All	2/21	2/23	10hr	100%
Attachment 2: Problem Formulation Technique	Ajay Haridasse and Jason Lu	2/22	2/23	4hr	100%
Attachment 3: Hours Log	All	2/23	2/23	1hr	100%
Attachment 4: Gantt Chart	All	2/22	2/23	1hr	100%
Town Hall Presentation	Andrew Hedberg	2/22	2/23	2hr	100%
Wrap-Up of P2M1 and Future Milestone Planning Meeting	All	2/23	2/23	1hr	100%
P2-Milestone 2	**PM 2**	**2/27**	**3/7**		**100%**
Initial Group Meeting with Mentor	All	2/27	2/27	1.5hr	100%
Intermediate Meeting (Progress Update)	All	3/1	3/1	1hr	100%
Final Meeting (Wrap-Up of P2M2 and Future Milestone Planning Meeting)	All	3/2	3/2	2.5hr	100%
Memorandum (Creativity Process)	Jason Lu	3/1	3/2	1.5hr	100%
Memorandum (Alternative Generation)	Ajay Haridasse and Jason Lu	3/1	3/2	3hr	100%
Memorandum (Updated Problem Statement)	Ajay Haridasse and Andrew Hedberg	3/1	3/2		100%
Attachment 1: Design Creation Process	All	2/27	3/2	6hr	100%
Attachment 2: Kepner-Tregoe Decision Analysis	All	3/2	3/2	1hr	100%
Attachment 3: Hours Log	All	3/2	3/2	0.5hr	100%
Attachment 4: Gantt Chart	Jacob Rabold	3/2	3/2	1hr	100%
Town Hall Presentation	Jacob Rabold	3/1	3/3	4hr	100%
Project Management Reflection	Jacob Rabold	3/3	3/7	3hr	100%

P2-Milestone 3	**PM 3**	**3/13**	**3/21**		**100%**
Initial Group Meeting	All	3/14	3/14	1.5hr	100%
Intermediate Meeting (Prototype Testing)	All	3/15	3/15	1hr	100%
Final Meeting (Wrap-Up of P2M3 and Future Milestone Planning)	All	3/16	3/16	2.5hr	100%
Prototyping	All	3/13	3/15	2hr	100%
Memorandum (Bill of Materials)	Andrew Hedberg	3/15	3/16	2hr	100%
Memorandum (User Experience)	Jason Lu	3/15	3/16	1.5hr	100%
Memorandum (Ideation Updates)	Jacob Rabold	3/15	3/16	1hr	100%
Memorandum (Updated Problem Statement)	Ajay Haridasse	3/15	3/16	1hr	100%
Attachment 1: CAD Drawings	All	3/15	3/16	3hr	100%
Attachment 2: Photo Log	Andrew Hedberg and Jacob Rabold	3/15	3/16	0.5hr	100%
Attachment 3: Bill of Materials	Andrew Hedberg	3/16	3/16	0.5hr	100%
Attachment 4: Electronics Flow Chart	Jason Lu	3/13	3/16	2hr	100%
Attachment 5: Hours Log	All	3/16	3/16	0.5hr	100%
Attachment 6: Gantt Chart	Ajay Haridasse and Jacob Rabold	3/16	3/16	1hr	100%
Town Hall Presentation	Ajay Haridasse	3/15	3/17	4hr	100%
Project Management Reflection	Ajay Haridasse	3/17	3/21	3hr	100%
P2-Milestone 4	**PM 4**	**3/21**	**3/28**		**100%**
Initial Group Meeting w/ mentor	All	3/21	3/21	1hr	100%
Material Gathering	Jacob Rabold	3/21	3/21	1.5hr	100%
Prototype Creation	All	3/21	3/22	4hr	100%
Electronics Coding	Jason Lu	3/22	3/23	5hr	100%
Final Meeting (Memo Discussion & Future Milestone Planning)	All	3/23	3/23	2hr	100%
Memorandum (Implementation - Documentation)	Jacob Rabold & Andrew Hedberg	3/23	3/23	1.5hr	100%
Memorandum (Proof of Concept)	Unassigned	3/23	3/23	2hr	100%
Memorandum (Evaluation Planning)	Ajay Haridasse	3/23	3/23	2hr	100%

Attachment 1: Wire Diagram	Jason Lu	3/22	3/22	1hr	100%
Attachment 2: Image Log	Andrew Hedberg & Jacob Rabold	3/22	3/23	0.5hr	100%
Attachment 3: Evaluation Plan Chart	Ajay Haridasse	3/23	3/23	2.5hr	100%
Attachment 3: Bill of Materials	Andrew Hedberg	3/22	3/23	0.5hr	100%
Attachment 4: Hours Log	All	3/23	3/23	0.5hr	100%
Attachment 5: Gantt Chart	Jason Lu & Jacob Rabold	3/23	3/23	0.5hr	100%
Town Hall Presentation	Jason Lu	3/23	3/24	2hr	100%
Project Management Reflection	Jason Lu	3/24	3/28	3hr	100%
P2-Milestone 5	**PM 5**	**3/27**	**4/6**		**100%**
Initial Group Meeting	All	3/27	3/27	1	100%
Memorandum: 90% complete prototype	All	3/28	4/2	4	100%
Memorandum: Evaluation and Feedback	All	3/31	4/4	4	100%
Memorandum: Design Review	All	3/31	4/4	2	100%
Project code	Jason	3/31	4/5	20	100%
Project construction	Ajay and Andrew	4/3	4/3	20	100%
Attachment 1: Wire Diagram	All	4/4	4/5	1	100%
Attachment 2: Image Log	All	4/4	4/6	1	100%
Attachment 3: Bill of Materials	All	4/4	4/5	1	100%
Attachment 4: Hours Log	All	4/5	4/6	1	100%
Attachment 5: Gantt Chart	All	4/5	4/6	1	100%
Town Hall Presentation	All	4/3	4/6	2	100%
P2-Milestone 6	**All**	**4/19**	**4/25**		**100%**
Prototype Construction	Ajay and Andrew	4/10	4/13	10hr	100%
Electronics Coding	Jason	4/10	4/13	10hr	100%
Event	All	4/14	4/14	1hr	100%
Memo: Description of Exhibit	All	4/13	4/14	2hr	100%

Memo: Description of function	All	4/14	4/16	2hr	100%
Memo: Description of educational elements	All	4/14	4/16	2hr	100%
Memo: Description of data collection	All	4/14	4/16	2hr	100%
Memo: Photo Log	Andrew	4/14	4/16	1hr	100%
Demo Video	All	4/15	4/16	2hr	100%

APPENDIX K – FINAL BUDGET

Project 1 Milestone 2: Bill of Materials								
Item	Unit Value	Units	Qty	Value	Cost	Source	MFR PN/Link	Notes
Plastic Water Bottles	$1.00	ea	5	$5	$0	Recycling	N/A	Used for the main body of the prototype.
Cardboard Boxes	$1.00	ea	2	$2	$0	Recycling	N/A	Used for the main body of the prototype.
Construction Paper	$0.50	ea	20	$10	$0	Already Own	N/A	Used for the main body of the prototype.
Tape	$2.50	ea	2	$5	$0	Already Own	N/A	To reinforce and secure the design.
Hot Glue	$0.50	ea	2	$1	$0	FYELIC	N/A	To reinforce and secure the design.
Hot Glue Gun	$10.00	ea	1	$10	$0	FYELIC	N/A	To put materials together

								as needed.
Scissors	$5.00	ea	1	$5	$0	Already Own	N/A	To cut paper or materials as needed.
				Totals:	$38.00	$0.00		

Project 1 Milestone 3: Bill of Materials								
Item	Unit Value	Units	Qty	Value	Cost	Source	MFR PN/Link	Notes
Smart Water Water Bottle	$2.00	ea	2	$4	$0	Recycling	N/A	Used for construction of final prototype
Dasani Water Bottle	$1.00	ea	1	$1	$0	Already Own	N/A	Used to construct prototype 1
Electrical Tape	$3.00	ft	5	$3	$0	FYELIC	N/A	Construction of final prototype
Scotch Tape	$3.00	ea	1		$0	Already Own	N/A	Used to construct initial prototypes (1,2,3)
Construction Paper	$0.50	ea	2	$1	$0	Already Own	N/A	Used to construct prototype 2
Toilet Paper Roll	$1.00	ea	1	$1	$0	Already Own	N/A	Used to construct

								prototype 3
Paper Towel Roll	$1.00	ea	1	$1	$0	Already Own	N/A	Used to construct prototype 3
Totals				$11	$0			

Project 2 Milestone 3: Bill of Materials								
Item	Unit Value	Units	Qty	Value	Cost	Source	MFR PN/Link	Notes
360 Degree Servo Motors	$7.50	ea	2	$15	$0	Professor O'Connell	https://a.co/d/cOOYRX3	Used to pull cars up ramp.
Arcade Buttons	$3.00	ea	4	$12	$0	Professor O'Connell	https://www.sparkfun.com/products/9336	For user's to select their answer to true or false question about solar energy.
Arduino Uno Redboard	$20.00	ea	1	$10	$0	SparkFun Kits	N/A	Used to control motors, LED's, arcade buttons.
Wood Sheets	$0.50	ea	60	$30	$30	Amazon	https://a.co/d/jdlmi1Z	Used for the main body of the prototype.
Solar Panels	$10.00	ea	2	$20	$0	Already Own	N/A	Used to simulate

								the usage of solar panels in our prototype.
LEDs	$0.25	ea	10	$3	$0	SparkFun Kits	N/A	Used to light up in front of solar panels to simulate an increase in solar power energy and increase in servo motor speed up the ramp.
Hotwheel's Cars	$2.50	ea	2	$5	$0	Already Own	N/A	To drive up the ramp and reach the finish line.
Tape	$3.00	ea	1	$3	$0	Already Own	N/A	To put materials together as needed.
Hot Glue Sticks	$0.20	ea	5	$1	$0	FYELIC	N/A	To put materials together as needed.
Hot Glue Gun	$13.00	ea	1	$13	$0	FYELIC	N/A	To put materials together

								as needed.
String	$2.00	ea	1	$2	$0	FYELIC	N/A	To attach to the 360 degree servo motors and the hotwheel's cars to pull hotwheel car's up the ramp.
			Totals:	$113.50	$30.00			

Project 2 Milestone 4 Bill of Materials

Item	Unit Value	Units	Qty	Value	Cost	Source	MFR PN/Link	Notes
360-Degree Servo Motors	$7.50	ea	2	$15.00	$0.00	Professor O'Connell	https://a.co/d/cOOYRX3	Used to pull cars up the ramp.
Arcade Buttons	$2.75	ea	5	$14.00	$0.00	Professor O'Connell	https://www.sparkfun.com/products/9336	For users to select their answer to the true or false questions about solar energy.
Arduino Uno Redboard	$20.00	ea	1	$10.00	$0.00	SparkFun Kits/Already Own	N/A	Used to control motors, LEDs, and

								arcade buttons.
Wires	$2.10	ea	1	$2.10	$0.00	SparkFun Kits/Already Own	https://www.sparkfun.com/products/12795	Used to connect different electronics to Arduino Uno Redboard.
Breadboard	$5.50	ea	1	$5.50	$0.00	SparkFun Kits/Already Own	https://www.sparkfun.com/products/12002	Completes the circuit for electrical connections between components.
Wood Sheet	$15.87	ea	1	$15.87	$15.87	Home Depot	https://a.co/d/jdlmi1Z	Used for the main body of the prototype.
Wood Dowels	$0.98	ea	2	$1.96	$1.96	Bookstore	N/A	To be attached to servo motor which is also attached to the string and hot wheels cars.
Solar Panels	$5.00	ea	2	$10.00	$0.00	Already Own	N/A	Used to simulate the usage

								of solar panels in our prototype.
LEDs	$1.50	ea	2	$3.00	$0.00	SparkFun Kits/Already Own	N/A	Used to light up in front of solar panels to simulate an increase in solar power energy and an increase in servo motor speed to pull Hot Wheel cars up the ramp.
Hot Wheels Cars	$1.19	ea	2	$2.53	$2.53	Target	Link here	To drive up the ramp and reach the finish line.
Tape	$3.00	ea	1	$3.00	$0.00	FYELIC	N/A	To put materials together as needed.
Wood Glue	$1.00	ea	1	$1.00	$0.00	FYELIC	N/A	To put materials together as needed.

String	$1.00	ea	1	$1.00	$0.00	FYELIC	N/A	To attach to the 360-degree servo motors and the Hot Wheels cars to pull Hot Wheel cars up the ramp.
			Totals:	$84.96	$20.36			
Project 2 Milestone 5 Bill of Materials								
Item	Unit Value	Units	Qty	Value	Cost	Source	MFR PN/Link	Notes
360-Degree Servo Motors	$7.50	ea	2	$15.00	$0.00	Professor O'Connell	https://a.co/d/cOOYRX3	Used to pull cars up the ramp.
Arcade Buttons	$2.75	ea	5	$14.00	$0.00	Professor O'Connell	https://www.sparkfun.com/products/9336	For users to select their answer to the true or false questions about solar energy.
Arduino Uno Redboard	$20.00	ea	1	$10.00	$0.00	SparkFun Kits/Already Own	N/A	Used to control motors, LEDs, and

								arcade buttons.
Wires	$2.10	ea	1	$2.10	$0.00	SparkFun Kits/Already Own	https://www.sparkfun.com/products/12795	Used to connect different electronics to Arduino Uno Redboard.
Breadboard	$5.50	ea	1	$5.50	$0.00	SparkFun Kits/Already Own	https://www.sparkfun.com/products/12002	Completes the circuit for electrical connections between components.
Wood Sheet	$15.87	ea	1	$15.87	$15.87	Home Depot	https://a.co/d/jdlmi1Z	Used for the main body of the prototype.
Solar Panels	$5.00	ea	2	$10.00	$0.00	Already Own	N/A	Used to simulate the usage of solar panels in our prototype.
LEDs	$1.50	ea	2	$3.00	$0.00	SparkFun Kits/Already Own	N/A	Used to light up in front of solar panels to simulate an

								increase in solar power energy and an increase in servo motor speed to pull Hot Wheel cars up the ramp.
Hot Wheels Cars	$1.19	ea	2	$2.53	$2.53	Target	Link here	To drive up the ramp and reach the finish line.
Electrical Tape	$3.00	ea	1	$3.00	$0.00	FYELIC	N/A	To put materials together as needed.
Wood Glue	$1.00	ea	1	$1.00	$0.00	FYELIC	N/A	To put materials together as needed.
String	$1.00	ea	1	$1.00	$0.00	FYELIC	N/A	To attach to the 360-degree servo motors and the Hot Wheels cars to pull Hot Wheel

								cars up the ramp.
3D Printed Holders and Dowels	$1.00	ea	4	$4.00	$0.00	FYELIC	N/A	To hold 360-degree servo motors and attach
Super Glue	$5.00	ea	1	$5.00	$5.00	Target	Link here	To reinforce weak areas and connect parts of prototype.
Laptop	$500.00	ea	1	$500.00	$0.00	Already Own	N/A	To run code and exhibit.
			Totals:	$592.00	$23.40			

Project 2 Milestone 5 Bill of Materials								
Item	Unit Value	Units	Qty	Value	Cost	Source	MFR PN/Link	Notes
360-Degree Servo Motors	$7.50	ea	2	$15.00	$0.00	Professor O'Connell	https://a.co/d/cOOYRX3	Used to pull cars up the ramp.
Arcade Buttons	$2.75	ea	5	$14.00	$0.00	Professor O'Connell	https://www.sparkfun.com/products/9336	For users to select their answer to the true or false questions about

								solar energy.
Arduino Uno Redboard	$20.00	ea	1	$10.00	$0.00	SparkFun Kits/Already Own	N/A	Used to control motors, LEDs, and arcade buttons.
Wires	$2.10	ea	1	$2.10	$0.00	SparkFun Kits/Already Own	https://www.sparkfun.com/products/12795	Used to connect different electronics to Arduino Uno Redboard.
Breadboard	$5.50	ea	1	$5.50	$0.00	SparkFun Kits/Already Own	https://www.sparkfun.com/products/12002	Completes the circuit for electrical connections between components.
Wood Sheet	$15.87	ea	1	$15.87	$15.87	Home Depot	https://a.co/d/jdlmi1Z	Used for the main body of the prototype.
Solar Panels	$5.00	ea	2	$10.00	$0.00	Already Own	N/A	Used to simulate the usage of solar panels in our prototype.

LEDs	$1.50	ea	2	$3.00	$0.00	SparkFun Kits/Already Own	N/A	Used to light up in front of solar panels to simulate an increase in solar power energy and an increase in servo motor speed to pull Hot Wheel cars up the ramp.
Hot Wheels Cars	$1.19	ea	2	$2.53	$2.53	Target	Link here	To drive up the ramp and reach the finish line.
Electrical Tape	$3.00	ea	1	$3.00	$0.00	FYELIC	N/A	To put materials together as needed.
Wood Glue	$1.00	ea	1	$1.00	$0.00	FYELIC	N/A	To put materials together as needed.
String	$1.00	ea	1	$1.00	$0.00	FYELIC	N/A	To attach to the 360-degree servo motors

								and the Hot Wheels cars to pull Hot Wheel cars up the ramp.
3D Printed Holders and Dowels	$1.00	ea	4	$4.00	$0.00	FYELIC	N/A	To hold 360-degree servo motors and attach
Super Glue	$5.00	ea	1	$5.00	$5.00	Target	Link here	To reinforce weak areas and connect parts of prototype.
Laptop	$500.00	ea	1	$500.00	$0.00	Already Own	N/A	To run code and exhibit.
Paint	$2.00	ea	4	$8.00	$8.00	Target	Link here	To paint exhibit,
			Totals:	$600.00	$31.40			

APPENDIX L – PROJECT HOURS LOG

P2-Milestone 1	Andrew Hedberg PM	Jacob Rabold	Ajay Haridasse	Jason Lu	Total
Initial Group Meeting	1	1	1	1	4
Memorandum (Research Summary)	0.5	0	2.5	2.5	3
Memorandum (Problem Statement)	0.5	0	0	0	3
Memorandum (Resources, Summary, and Works Cited)	0.5	0	0.5	0.5	2
Attachment 1: Individual Background Research	2	1	2	2	8
Attachment 2: Problem Formulation Technique	0.5	0	1.5	1.5	3.5
Attachment 3: Hours Log	0.5	0.5	0.5	0.5	2
Attachment 4: Gantt Chart	0.5	0.5	0.5	0.5	2
Town Hall Presentation	2	0	0	0	3.5
Wrap-Up of P2M1 and Future Milestone Planning Meeting	1	1	1	1	4
Totals:	9	4	9.5	9.5	35
P2-Milestone 2		PM			
Initial Group Meeting	1.5	1.5	1.5	1.5	6
Intermediate Meeting (Progress Update)	0.5	0.5	0.5	0.5	2
Final Meeting (Wrap-Up of P2M2 and Future Milestone Planning)	2.5	2.5	2.5	2.5	10
Memorandum (Creativity Process)	0	0	0	1.5	1.5
Memorandum (Alternative Generation)	0	0	1.5	1.5	3
Memorandum (Updated Problem Statement)	1	0	1	0	2
Attachment 1: Individual Idea Generation	1.5	1.5	1.5	1.5	6
Attachment 2: KTDA chart	1	1	1	1	4
Attachment 3: Hours Log	0.5	0.5	0.5	0.5	2
Attachment 4: Gantt Chart	0	1	0	0	1

Town Hall Presentation	0	4	0	0	4
Totals:	8.5	12.5	10	10.5	41.5
P2-Milestone 3			PM		
Initial Group Meeting	1	1	1	1	4
Intermediate Meeting (Prototype Testing)	0.5	0.5	0.5	0.5	2
Final Meeting (Wrap-Up of P2M3 and Future Milestone Planning Meeting)	2	2	2	2	8
Prototyping	0	0	2	2	4
Memorandum (User Experience)	1.5	0	0.5	0	2
Memorandum (Ideation Updates and Electronics)	0	0	2	0	2
Memorandum (Updated Problem Statement)	0	0	1	0	1
Attachment 1: CAD Drawings	2.5	2.5	2.5	2.5	10
Attachment 2: Photo Log	1	0.5	0.5	0	2
Attachment 3: Bill of Materials	1	0	0	0	1
Attachment 4: Electronics Flow Chart	0	0	0	1	1
Attachment 5: Hours Log	0.5	0.5	0.5	0.5	2
Attachment 6: Gantt Chart	0	0.5	0.5	0	1
Town Hall Presentation	0	0	2	0	2
Totals	10	7.5	15	9.5	42
P2-Milestone 4				PM	
Initial Group Meeting w/ mentor	1	1	1	1	4
Material Gathering	0	1.5	0	0	1.5
Prototype Creation	4	4	1	1	10
Electronics Coding	0	0	0	5	5
Final Meeting (Memo Discussion & Future Milestone Planning)	2	2	2	2	8
Memorandum (Implementation - Documentation)	1.5	1.5	0	0	3
Memorandum (Proof of Concept)	0	0	1.5	0	1.5

Memorandum (Evaluation Planning)	0	0	2	0.5	2.5
Attachment 1: Wire Diagram	0	0	0	0.5	0.5
Attachment 2: Image Log	1	0.5	0	0	1.5
Attachment 3: Evaluation Plan Chart	0	0.5	1	0.5	2
Attachment 3: Bill of Materials	1	0	0	0	1
Attachment 4: Hours Log	0.5	0.5	0.5	0.5	2
Attachment 5: Gantt Chart	0	0.5	0	0.5	1
Town Hall Presentation	0	0	0	2	2
Totals	11	12	9	13.5	52
P2-Milestone 5					
Initial Group Meeting	1	0	1	1	3
Prototype Code	0	0	0	15	15
Prototype Building	10	0	8	2	22
Memorandum (Overall Prototype Documentation)	2	0	1	0	3
Memorandum (Evaluation Planning)	0	0	2	0	2
Attachment 1: Photo Log	0.5	0	0	0.5	1
Attachment 2: SolidWorks Ramp Layout Plan	1	0	0	0	1
Attachment 3: Wire Diagram	0	0	0	0.5	0.5
Attachment 4: Flowchart	0	0	0	0.5	0.5
Attachment 5: Updated Bill of Materials	0.5	0	0.5	0.5	1.5
Attachment 6: Hours Log	0.5	0	0.5	0	1
Attachment 7: Gantt Chart	0.5	0	0.5	0.5	1.5
Totals	16	0	13.5	20.5	52
P2-Milestone 6					
Prototype Code	0	0	0	7	7
Prototype Construction	6	0	4	5	15
Memorandum (Exhibit Description)	0	0	1.5	0	1.5

Memorandum (Primary Functional Elements)	0	0	1	0	1
Memorandum (Passive Educational Elements)	0	0	1	0	1
Memorandum (Data Collection)	0	0	1	0	1
Attachment 1: Photo Log of 100% Complete Prototype	0.5	0	0	0.5	1
Attachment 2: Demo Video	0	0	0	1.5	1.5
Attachment 3: Updated Bill of Materials	0.5	0	0	0	0.5
Attachment 4: Hours Log	0.5	0	0.5	0.5	1.5
Attachment 5: Gantt Chart	0.5	0	0	0	0.5
Totals	8	0	9	14.5	31.5