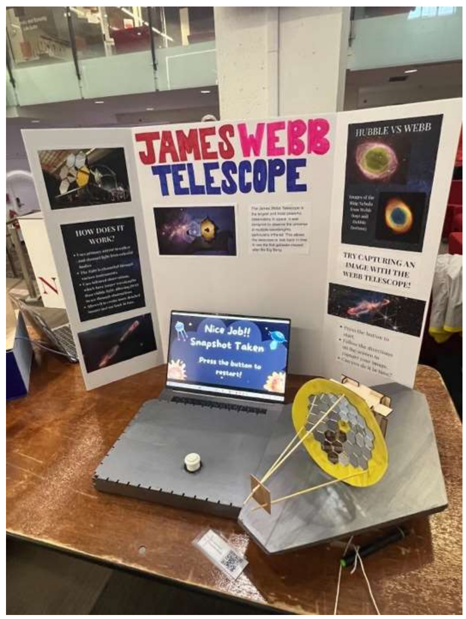
Northeastern University
College of Engineering

Cornerstone of Engineering I & II
Spring 2024

Webb Telescope Museum Exhibit



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ABSTRACT

Our client requested a portable museum exhibit to address the lack of hands-on teaching materials for rural and underprivileged communities. This exhibit is meant to educate middle to high school aged students on the science and technology behind space exploration in an engaging and interactive way. The client required the final design to fit on a 28” x 36” table and be portable in a large tote bag. The final value must be under $1000 and final cost under $100. We are mainly catering to students and teachers so the exhibit should be durable and safe, during use and transportation.

Our solution is an interactive model on the James Webb Space Telescope. Our model replicates the telescope’s function by collecting light through a larger primary mirror, reflecting it onto a smaller secondary mirror and onto a photocell. The exhibit displays an image that slowly pixelates as the user successfully reflects the light, demonstrating how the Webb Telescope takes pictures. The activity has a five-second time limit to make it more game-like; the user wins if the picture is entirely clear before the time runs out. The model is aided by information presented on a poster to further explain the telescope's use and function. Through the peer feedback form we were able to measure the educational engagement of the exhibit. 100% of responses reported that they would use our exhibit again and 80% said that our exhibit was educational. From this information we were able to conclude that our exhibit was successful in being interactive. We addressed the educational component by adding the poster board, however we observed that most users did not interact with or pay attention to the information on the board.

Table of Contents

List of Tables

List of Figures

AASHNA SAHANI

1 INTRODUCTION

1.1 PROBLEM STATEMENT

The problem to address is the limited accessibility of STEM-focused museums for children living in rural areas, compounded by their limited opportunities to visit such institutions. As many schools in these regions lack the funding to bring students out to museums, bringing a similar resource to them is necessary. Our client requested a portable space exploration museum exhibit that will give these middle and high school students a similar experience to a real museum.

It is important that the exhibit is engaging and interactive for the students. The article, "Engagement with an Interactive Museum Exhibit", suggests that the most successful and engaging museum exhibits have a game-like aspect and put the user in control [9]. Our research of the Franklin Institute further underscores the importance of hands-on activities in sustaining the user's interest and immersing them into the exhibit's environment. For instance, in their exhibit "Wondrous Space", visitors encounter numerous interactive activities designed to deepen their understanding of the topic. "Suit Up!" stands out as a prime example of this, allowing users to craft their own space suits capable of withstanding various planetary conditions [16]. The exhibit's effectiveness comes from its ability to empower users to actively participate in their learning experience.

To reach the goal of engaging, we will focus on a visually appealing model along with a game-like activity. Besides being engaging and interactive, it is also important that our exhibit is educational and portable to reach our client's goal of spreading education to students in rural communities. We want to teach the students about something they do not learn about in school, which will be accomplished by choosing a unique topic to focus on. As requested by the client, the design must also be 36" by 28" when set up, safely transportable in a large bag, safe for younger children to use, and less than $1000.

1.2 STAKEHOLDERS

The primary stakeholders for this issue are the client and user as they are most directly involved with the development and utilization of the exhibit. While our client initially visualized this product as a museum alternative, this product also holds potential as an in-class activity. Therefore, secondary beneficiaries include teachers and other educators who may adopt this product as an alternative teaching method.

From a financial perspective, the client holds the greatest significance as a stakeholder. Additionally, the client is a primary stakeholder since our product will be designed to meet their goals. They also brought up the issue and have a general visualization of what the product should be. Our design will be created following the needs and constraints of the client; however, we will take these ideas and expand them to incorporate our own goals.

On the other hand, the impact of the product's functionality is more dependent on the user, as in the students. The user is a primary stakeholder because their learning experience and engagement determine the success of the product. Safety is also a large concern when it comes to the user as the product will have wires and electronic parts that should be hidden from children. If the students do not enjoy or learn from the exhibit, then the product did not achieve its goals, therefore, it is important to understand the user's preferences and needs.

1.3 SCOPE

This technical report aims to analyze the process taken to create a solution to address this problem. The report will delve into the idea generation, prototyping, electronics, and feedback that resulted in our final design.

2 BACKGROUND

2.1 RESEARCH

To better understand our client's problem, we did some background research that broadly addressed the problem. We decided to investigate successful science museum exhibits along with teaching methods for younger children to identify some common themes to incorporate into our exhibit. We also chose a variety of space exploration topics to narrow down some of our ideas.

Our research on children's space exhibits helped us understand what makes an exhibit engaging and how to best incorporate interactive elements into the exhibit. The Franklin Institute has a variety of exhibits that teach children on different topics of space exploration. Each exhibit has multiple interactive elements that allow the children to immerse themselves in each activity. One exhibit, "Design a Rover", allows children to customize and launch a rover to their chosen destination, teaching them about the different aspects of rovers in an entertaining way [16]. This exhibit is especially successful because it utilizes the children's imagination and a game-like activity to keep them engaged. Further research also suggests that limiting the exhibit to one or two tasks helps to not confuse the children. Reducing distractions and increasing the children's ability to participate in the activity are important [9]. This research also showed the importance of balancing education with entertainment since our main users are middle to high school students.

We also learned helpful techniques to make our exhibit more eye-catching for children by adding visually appealing elements, such as in the Boston Museum of Science "Cosmic Light Exhibit" which shows large displays of celestial bodies [15]. The exhibit's appearance is the first thing children notice so including simple, yet colorful and unique displays would draw them in.

While we researched some broad topics, such as rovers, rockets, and the history of space exploration, we decided to focus on the James Webb Telescope. We chose this topic because it is a much more unique topic that has not been covered in many museums nor in most schools. Our goal is to expand the students' knowledge past what they are learning in class, which is met by teaching them about a newer piece of space exploration technology. The Webb Telescope is the largest and most complex telescope that has ever been sent to space and is a more advanced version of the Hubble Space Telescope. It captures images of space using light reflection and cameras and sensors. The Webb Telescope collects infrared light waves rather than ultraviolet light, setting it apart from the Hubble Telescope. The light waves reflect off the primary mirror, a large honeycomb of hexagonal mirrors, onto the secondary mirror, which then reflects a more focused beam of light onto the cameras and sensors behind the primary mirror. The telescope is even able to capture images of space from the past [7].

2.2 ETHICS

To address any ethical concerns or implications, we focused on our user's needs and behaviors by creating an empathy map. Since we are working with younger children, safety and durability are incredibly important for both our users and our product. As there will be interactive Arduino elements in the exhibit, there will be wires and other electronic parts that we will keep away and hidden from the children to avoid any harm to the children or exhibit. From a virtue-oriented standpoint, we want to successfully educate and teach the children something new. We plan to foster their curiosity and knowledge by introducing them to content not taught in school.

2.3 UNIVERSAL DESIGN

The purpose of Universal Design is to create a product that can be used to the greatest extent by the largest range of people [30]. While our main users are middle to high school students, we must consider children of all educational levels and disabilities to broaden our audience. Our product does not address everyone, such as those who are visually impaired, mostly due to constraints such as resources and budget. However, we believe that our product is simple enough to be used by a variety of users and contains different types of information, both written and interactive elements, to promote different methods of learning.

3 METHODOLOGY

3.1 PROBLEM DEFINITION

Our problem statement confirmed the goals and constraints of our client's problem along with additional goals we would like to address. The main criteria our product must meet is that it must be a museum exhibit on space exploration that is educational, engaging/interactive, portable, must introduce the students to a new topic, and is visually appealing. To expand on these goals, we conducted further research to aid us in our solution generation. We split the research into different categories to avoid repetition: successful museum exhibits, rovers, rockets, and the history/current news of space exploration.

By researching museum exhibits on space and successful engagement with children, we were able to expand our criteria to create a clearer path to a solution. Our research of the different potential topics was not as useful, but still provided us with a solid foundation to come up with more specific ideas.

We also used an empathy map to consider specific constraints of our user, especially considering the age range we are working with. We also created a KTPA chart to help narrow down the general problem. By going through these processes, we were able to identify constraints such as simplicity, durability/safety, and education versus entertainment.

Through our research we decided to stick with one main game-like activity for simplicity's sake. This competitive aspect will also make the exhibit more entertaining for the students as it will motivate them to interact with it multiple times. By sticking to one main idea, we can also focus on educating the students very clearly with little confusion and distraction.

3.2 SOLUTION GENERATION

To create a variety of solutions, we used two main methods of idea generation: lateral thinking and vertical thinking. Lateral thinking helped with the initial idea formulation since it functions as a word association process. For our second method, we chose vertical thinking because it helped us expand on ideas we already came up with. It was also a relatively straightforward process for this problem since it was easy to substitute Arduino elements and choose different topics within the scope of the James Webb Telescope. We each came up with two to three ideas each so that we would have a broad range to choose from.

While using lateral thinking, I used the words "evolution" and "stove" to create one of my initial ideas. These words led me to think of using the images taken by the telescope as a timeline that is controlled by the user using a servo or potentiometer. This first idea can be seen in Figure 1.

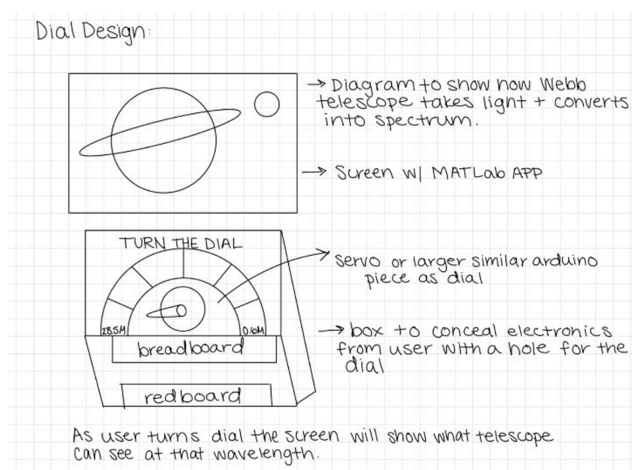

Figure 1. Dial Design Initial Sketch

Next, I used vertical thinking, or the SCAMPER method, to substitute and modify some elements and create a second idea. I stuck with the idea of using images taken by the telescope but modified the idea from a timeline to just a range of visually appealing images. I also substituted the potentiometer for a photocell to mimic the real telescope's use of light waves. Lastly, I adapted the physical appearance of the product to look like the telescope instead of just being a display and knob. This idea can be seen in Figure 2.

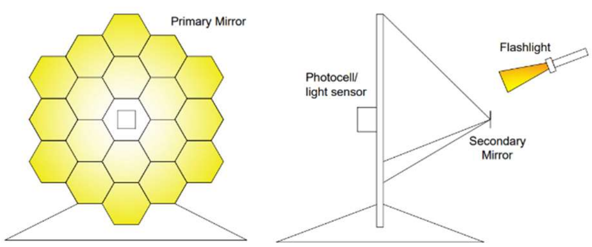

Figure 2. Model Telescope Design Initial Sketch

3.3 DECIDING ON A SOLUTION

After coming up with this broad range of ideas, we made a rank order chart to come up with our main goals and the ranking of these goals. We chose interactive/game-like, educational, portable, attainable, and durable/safe as our most important goals to rank. Most of these goals aligned with the objectives of our client, however we added attainable to our list as our team had struggled with creating an attainable design for our last project. This rank order chart can be seen in Appendix K as Table 1.

We decided on our solution by using a Kepner Tregoe Decision Analysis chart and ranking each design against our ranked goals. We measured durability and safety based on how many electronic components would be used and how delicate the design would be. We measured attainability by how complex the physical structure would be to create along with the complexity of the code. Educational was measured by how relevant the design was to the topic of the Webb Telescope and how much information it could show. Interactive and game-like was assessed by whether the design was competitive or entertaining for children to use. Lastly, portability was evaluated by the size of the design and the number of parts. This chart can be seen in Appendix K as Table 2.

The Model Telescope, as seen in Figure 2, was ranked the highest out of all of the ideas and felt the most interesting to us as well as it was the most unique.

3.4 IMPLEMENTATION

To begin creating our final design, we made AutoCAD sketches with complete dimensions and different angles of the products. We scaled down the dimensions of the real telescope about 40:1 to keep proportions accurate. Creating front, top, side, and travel configuration view sketches allowed us to follow to our size constraints and visualize different elements of the design.

Once we created our sketches, we were able to move on to our cardboard prototype which can be seen in Figure 3. The base, both mirrors, and box for electronics were all created out of cardboard and hot glue. The primary mirror and secondary mirror were connected using wooden dowels. With this prototype in place, we were able to identify areas that required additional reinforcement. We also discussed what materials we would want to use for each part, for example the primary mirror is slightly conical, so we had to find a material that was both durable and flexible.

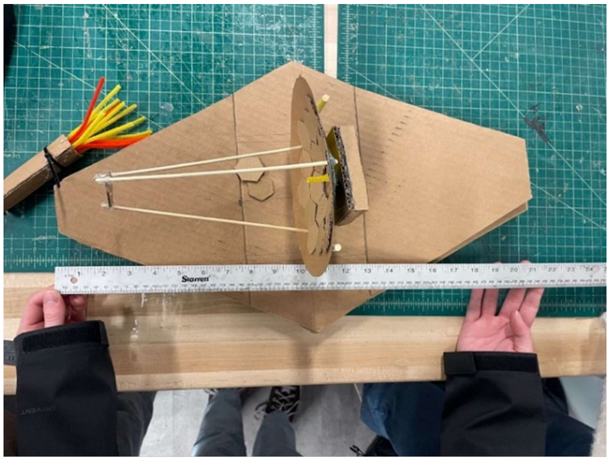

Figure 3. Top view of cardboard prototype

With the cardboard prototype in place, we created a flowchart, as seen below in Figure 4 to visualize our program and user interface. This helped us create an outline for our code and understand the general structure of it.

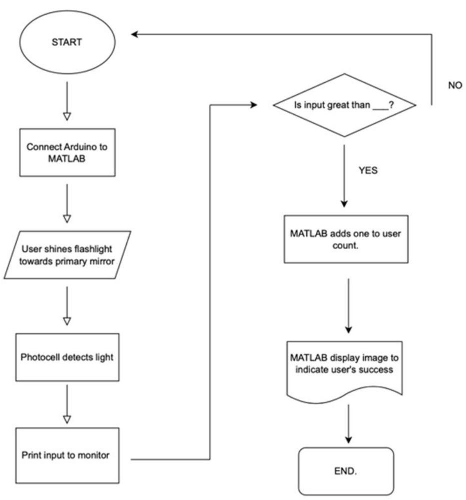

Figure 4. Flowchart of program and user experience

Our next step was to create our proof of concept. We began replacing cardboard elements from our initial prototype with more durable materials such as wood. We focused on creating the primary and secondary mirror for this milestone since these were essential to the function of our product. We tested the reflection of the mirrors and whether the photocell would pick up light. Our testing of this can be seen in Figure 5.

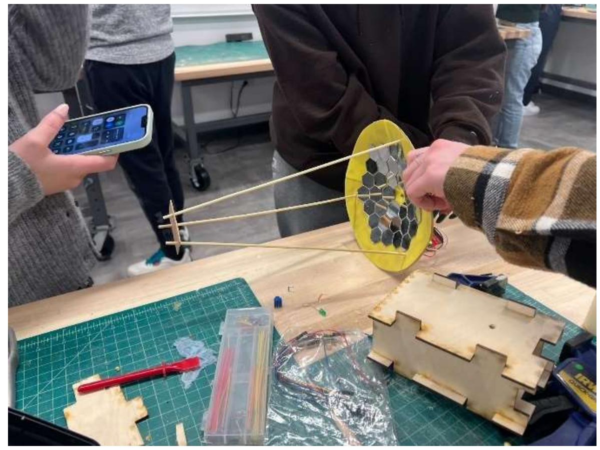

Figure 5. Testing of light reflection of primary and secondary mirrors

The other portion of our proof of concept was the code. The wiring of our design can be seen in Appendix F, and was relatively simple since initially, our only Arduino component was a photocell. Our initial code sent the photocell's light values to MATLAB, which then displayed an image. This image was initially very pixelated but as the user shines the light for longer, the image became clearer.

For milestones 5 and 6 we continued to finalize our design, replacing, and adding any remaining elements. We added boxes for our electronics, one behind the primary mirror for the photocell, and one below the base for additional wiring. We also finalized our code and added some additional elements which will be detailed later in this report. Lastly, we finalized the aesthetic portions of the product by painting the base and creating a poster. The build process can be seen in Figures 6 and 7, and the final product can be seen in Figure 8.

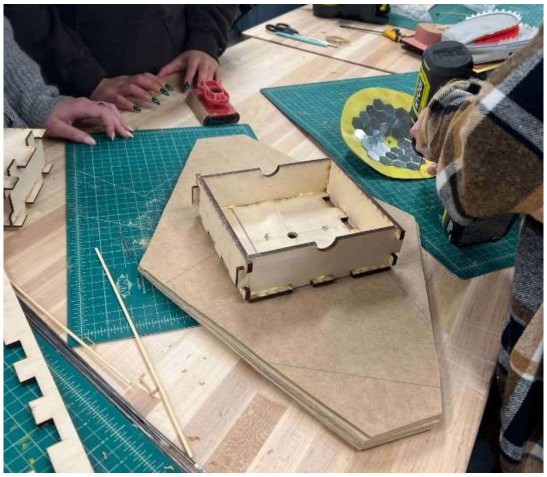

Figure 6. Underside of base with box for wiring

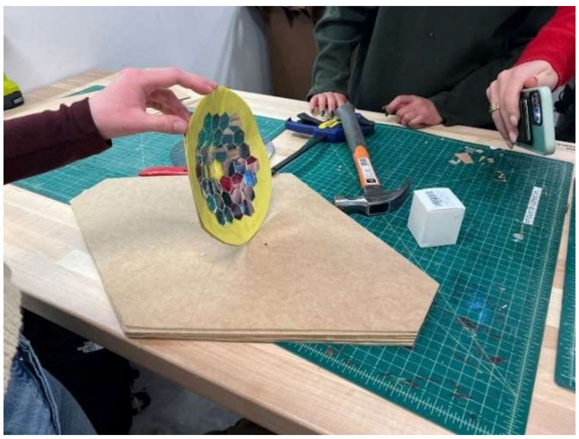

Figure 7. Detached primary mirror and base

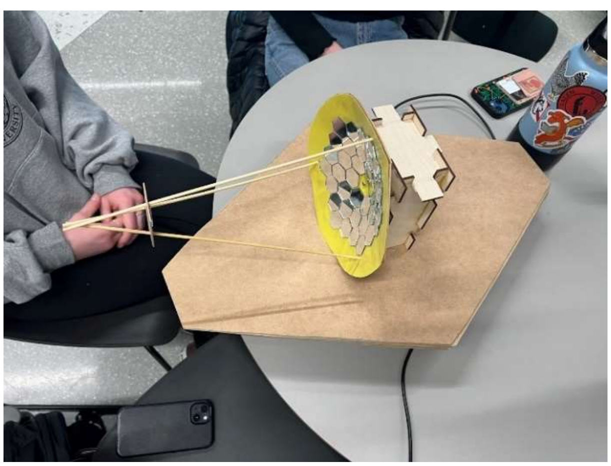

Figure 8. Final design before final aesthetic touches

3.5 EVALUATION

Throughout the next couple of weeks, we continued to edit our code and improve the physical aspects of our design. Most of our focus went towards our code since improving that portion of our exhibit would increase the overall engagement level. We did most of this testing on our own since we just wanted to see how well the reflectivity of the mirrors and our code worked.

For our in-class gallery walk we included a form that our peers could fill out which asked about the engagement, educational, and difficulty level of the exhibit. The most prominent changes to our design that came from this process was the addition of a five second time limit for the user to complete the activity along with a restart button to make the exhibit more engaging and game-like.

3.6 INDIVIDUAL CONTRIBUTIONS

For Milestone 1, I chose to research NASA's current projects and the history of space exploration. During my research I came across the James Webb Telescope. After introducing and explaining this topic to my team, we decided to focus on it for our exhibit.

During solution generation, I created the dial design which can be seen in Figure 1. Using ideation methods, I also created the model telescope design which can be seen in Figure 2. This was the idea we ended up choosing for our final design, as seen in Table 1 in Appendix K.

For Milestone 2 of our design, I contributed to the physical build as well as the planning of the exhibit. We all created an AutoCAD sketch of the prototype, and I created the front and back view of the design as seen in Figure 27, in Appendix C. For the cardboard prototype, I helped cut and attach the base and mirrors. These elements can be seen in Figure 34 in Appendix G. I also suggested the use of hexagonal mirror tiles for the mirrors since there was no way for us to cut the tiles ourselves.

Once we began creating the final design, I was responsible for most of the Arduino and MATLAB code which can be seen in Appendix E. I created a functioning program that displayed a largely pixelated image which slowly became clearer when the photocell collected light. I also helped with the physical model for our exhibit. I assisted in creating the primary mirror and suggested the flexible plastic material used for the backing of the mirrors.

For the final milestones, I continued to work on the code by myself. I worked on getting the UI figure and images to display in full screen. I then added the time limit element to the game. I also fixed our code so that it would stop pixelating if the photocell was not collecting light. Lastly, I added a button element to the Arudino and made the MATLAB program restart the game if it was clicked. I also created, found, and added all the images used in the MATLAB user interface, which can be found in Appendix H. These changes were all made to make the exhibit more game-like and to increase the difficulty of the game. I also helped with the final structural changes we made to the design. I helped attach the laser cut boxes together and attach the electronics to their respective boxes.

CARLY ROBINSON

4 INTRODUCTION

4.1 PROBLEM STATEMENT

The problem is that the client is in need of a portable science museum exhibit targeted to teach middle and high schoolers about space exploration related topics. The client has requested an interactive learning experience to educate this age range about STEM concepts. This exhibit should be able to be used by many people, transported to a new location, set up, and used all over again.

The article, "Engagement with an Interactive Museum Exhibit", describes that children engage most with a museum exhibit that has game-like technology and allows the user to feel in control [9]. The Franklin Institute is a reputable children's science museum with many successful exhibits which provide inspiration for this project. Their exhibit, "Wondrous Space", has many interactive activities for visitors to engage in and strengthen their understanding of the topic. One specific activity from this museum is 'Suit Up!' and allows users to design their own space suit which can withstand the elements of their destination. A game like this allows the user to feel in control as they are making their own decisions. The user can dictate their experience with the exhibit and engage more with it. Since the user is creating a suit to withstand the conditions of different destinations, the game tests their understanding of different environments in space. This creates a knowledge recall aspect that could be incorporated for this client's final product. The Franklin Institute is very successful because it creates exhibits with many different activities like this that test the user on different content presented [16].

There are a variety of museum exhibits and in-class activities to teach students about topics such as space exploration, however there are limited portable designs. One applicable example is a school bus in India that was converted into a traveling museum and can be used as inspiration for a portable exhibit. While this is a much larger scale than our client's request, this museum keeps more delicate items in cases highlighting the importance of durability and safety. They also have activity sheets and handouts, which is a form of recall for the user, seen in many different museums [21].

The client provided a few constraints: 36" by 28" when set up, transportable in a specific configuration, containing educational text with titles and other important information, safe for user and transport, and total cost under $1000. Considering initial information, the solution should have educational content that is clearly presented to a user on a poster board with plenty of visual and written guides such as captions. The solution should also have a game-like activity that allows the user to feel in control and promotes engagement which will be measured through tracking user interaction. There will also be a recall element to solidify the user's understanding, and protection measures will be taken to ensure durability and safety by hiding all electronic components and wires.

4.2 STAKEHOLDERS

For this design, the primary stakeholders are the clients and users. There are also secondary stakeholders that are also important to recognize. These secondary stakeholders include professors and similar educators, Cornerstone of Engineering peers, and the First Year Engineering Learning and Innovation Center.

The clients have requested a design that meets all their wants and needs for the users to learn more about space exploration. They have pre-determined their problem and have hired our team to come up with a solution to this problem. The client's needs are heavily considered during all steps of the engineering design process.

The users are also another prevalent stakeholder that has an important role in the design of the project. The project is designed for their enjoyment and learning, which contributes to many design decisions throughout the engineering design process. The users are within a certain age range, so it is important to keep in mind the limitations and capabilities of this demographic.

Professors and other similar educators are secondary stakeholders because they also have specific requirements for the project to ensure its success. In addition, the course curriculum and material played a role in guiding our team to our final project. This impacts the project because our team must refine our ideas for our final solution to fit this criterion and the curriculum of the course.

The First Year Learning and Innovation Center is also a secondary stakeholder because this resource has access to a variety of tools and materials. However, there is only a certain amount of these tools and materials considering this resource's access and quantity shared between all first-year engineering teams. This plays a role in the outcome of the final design due to the overall shared use of these materials and their quantity.

4.3 SCOPE

This technical report aims to detail the steps taken throughout our team's engineering design process to address the problem for the client and its users.

5 BACKGROUND

5.1 RESEARCH

Our team began our background research to be able to gain extensive knowledge of the ways in which we would begin addressing the problem. We divided the areas of background research into 4 groups: rovers, rockets, history of space travel, and children's space exhibits. We divided our research into these groups to be able to find examples that we could gain inspiration from for our design. It also allowed for more related information in we could build our project.

The background research regarding rovers and rockets were more specific topics within our research process but provided our team ways in which we could incorporate interactive, educational elements into our design. Some overall concepts that we found that are interactive for users are detection of objects, goal-oriented missions, and overall importance of cameras and their locations of space exploration machines [1, 2, 5].

The background history of space travel was an important topic for our team to gain more information for the project. It allowed us to have an understanding of the importance of various findings and prevalent space exploration topics from NASA. The background history of this topic also allowed our team to understand the ways in which we could incorporate educational elements into our design for the users. This research allowed us to understand our users' attitudes and the best educational techniques for their learning. Specifically, we learned that children learn best when they are surrounded by a stimulating environment. This can be accomplished through creativity, visually appealing designs, and interactive aspects [9, 10].

Since our design is geared towards a younger audience, it was crucial for our team to have a better understanding of the current exhibits designed for this audience. Of the research that we conducted, a few of the successful exhibits that we found were the Boston Museum of Science and the Franklin Institute. One specific universe exhibit in the Boston Museum of Science is the "Cosmic Light: Revealing the secrets of the universe" exhibit. This exhibit analyzes the wavelengths of light and displays color photographs for the user, thus showing key information such as star births and deaths. This was an important reference for our project because our solution is related to the wavelengths of light and being able to adequately capture a photograph with the sensed data from the flashlight [15]. The Franklin Institute was another important museum that we could gain inspiration from for our project. The "Suit Up!" exhibit was one example where we gained inspiration from, specifically through a game-like, interactive exhibit for the users.

Considering the current NASA projects and interactive exhibit, our team decided to base our solution off the James Webb Telescope. The James Webb Telescope orbits the sun and is an infrared observatory that is an adapted version of the Hubble Space Telescope. The Webb Telescope was launched on December 25, 2021, and its mission is estimated to last for around 5-10 years. The Webb Telescope captures images to find more information about the universe's stars and galaxies.

5.1 ETHICS

Making important ethical considerations was an important aspect of our engineering design process. One of the aims of our project was to ensure that all users enjoyed it and it did not negatively impact them. One technique we used to maximize the positive experience for our users was to create an Empathy Map (see Appendix B). By creating this map, it allowed us to have a better understanding of our users and how we can better formulate our problem statement to support them. After completing the Empathy Map, we realized that it allowed us to recognize our biases, hidden assumptions, errors, and implied solutions that we were bringing into the project. Going forward, we considered our decisions with more of an ethical viewpoint and prevented any unethical design decisions. We were able to pay attention more to the demographic differences between our team and the users, which will benefit in making the final design.

5.2 UNIVERSAL DESIGN

The universal design is used for the purpose of an all-inclusive design for the users. The design should be able to be inclusive through areas such as accessibility, comprehension, and other aspects that encourage all users easy use of the design [29].

This was an important consideration when building and designing our project because our team wants all users to be able to easily use the device and encourage all users to learn about space exploration. The Empathy Map (see Appendix B) was one way in which our team addressed making the design inclusive for all users. This brought to light the abilities and limitations of our users that we would need to consider throughout the engineering design process. Some of these limitations include the difference in knowledge, height, and overall interests. By keeping these limitations and abilities in mind, we can create the final design that better fits the user and their needs when interacting with the design.

6 METHODOLOGY

6.1 PROBLEM DEFINITION

To effectively define the problem, we split up the research into four categories: successful museum exhibits, the history of space exploration/current projects, rovers, and rockets. We chose rovers and rockets as two of our categories because they are two very classic forms of space exploration technology that children are aware of/interested in, and because there are constantly new developments in these areas.

After completing this research, we completed our Kepner Tregoe Problem Analysis (KTDA) chart to analyze the problem even further (see Appendix K). The main aspects of the problem were that we must create a portable museum exhibit that educates middle and high school students about some topic regarding space exploration. We need to make sure to aim the exhibit and content toward this age range to ensure that the design is engaging and at the appropriate teaching level. We also need to make sure our exhibit can be set up easily and is a durable design that can withstand children constantly using it. This makes sure that the design is safe for children to use and does not pose any hazard while interacting with the design. In addition, we need to make an exhibit that is both fun and educational for the children to engage and interact with.

Through our research, some ways to promote engagement and interaction included creating a sense of competition or a game-like activity. Successful exhibits also seemed to include the children as part of the 'storyline' such as the Franklin Institute's 'Suit Up!' exhibit where users design their own space suit to withstand the elements of their destination [16]. The "Cosmic Light: Revealing the secrets of the universe" exhibit in the Boston Science Museum is another exhibit that promotes interaction [15].

6.2 SOLUTION GENERATION

Our team decided to use the lateral thinking and vertical thinking approach for generating ideas for the design. Lateral thinking allowed us to create a broad range of designs because it helped us formulate our initial designs. We used a random word generator or random words in our vicinity to come up with unique ideas that could help our team solve the client's problem. Our team also used the SCAMPER method for vertical thinking because we could come up with alternative designs of each of our initial ideas to expand the design variability. By using this approach, we were able to analyze in more detail the variety of designs. This would allow more solutions that could best support our client. We also looked back to our research and our client's needs, so we could come up with a diverse assortment of potential solutions for our client.

For one of my designs, I used a random word generator to come up with the words "restrict" and "canvas". From there, I created my first design in relation to these two words. I incorporated "restrict" by restricting the amount of small, hazardous pieces in the design that could harm the users. When using a large object to simulate a distant galaxy, the user does not have to be concerned about the small, delicate pieces that are involved with this design. This can be seen in Figure 9.

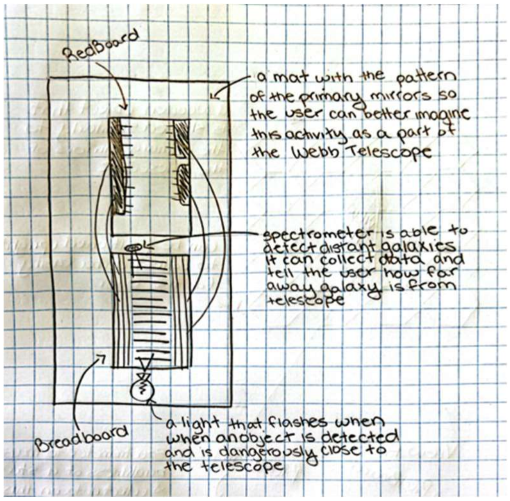

Figure 9. Object Detection Generated Design Idea

In my second design, I used the vertical thinking approach and substituted a light with a camera. In addition, I also rearranged the design so that the RedBoard and breadboard would be behind the primary mirrors to allow an easier, more simple design for the user and whoever sets up the design. This is seen in Figure 10.

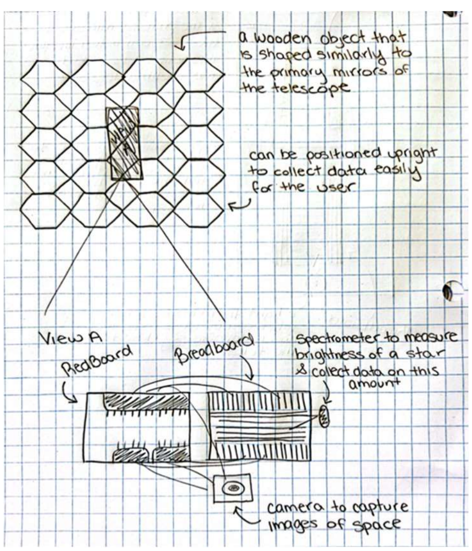

Figure 10. Camera Generated Design Idea

6.3 DECIDING ON A SOLUTION

After our team came up with a list of ideas, we then used the Rank Order Comparison Analysis method to come up with a qualitative analysis and scoring of each objective. For the objectives, we came up with a list: safety/durability, attainability, education, interactivity, and portability.

We included safety because we want to make sure that nobody is injured from using our design and this objective was also specifically required of the client. Durability also goes in-hand with this objective because if the device is not durable, it poses a safety hazard for the user. Attainability was another important objective because we want to make a fully functional design for our client and the users. In our first project, we struggled with attainability, and we wanted to keep this objective in mind for this current project. Education is another important objective because this is a requirement of the client, and we also want the users to leave with a better understanding of space exploration after using the design. Engagement is similar to education, however we included this as an objective because it allows the users to want to use our design more. Finally, portability was our final objective that we thought was important for our final design. This objective was specifically mentioned by our client, and we also wanted to make the design as easy as possible to get around. We then came up with the final Rank Order Comparison Chart as seen in Appendix K.

We then came up with a Kepner Tregoe Decision Analysis Chart to rank all our designs and determine which design would best fit all the objectives to fit the client’s needs. After completing this chart, we determined the Model Telescope design scored the highest out of all the designs. Our KTDA can be referenced in Appendix K and the

Model Telescope Design can be seen in Appendix C, Figures 37, 38, 39, and 40.

6.4 IMPLEMENTATION

We first began by designing AutoCAD sketches to gain a better idea of how we would begin to approach building our design. This allowed our team to understand the dimensions of our prototype and the materials that we would need for the prototype and eventually the final design. These sketches can be seen in Appendix C.

We then created a prototype out of cardboard, wooden dowels, and hot glue. There were no major issues that arose from this prototype; however, we did recognize areas in which we wanted to improve certain aspects. For example, we put more consideration into the dowels for the secondary mirror and the technicality of attaching the secondary mirror in our final design. The prototype was designed at a 1:40 scale, which our final design will be based off, compared to the actual James Webb Telescope. Photos of the building and our final cardboard prototype can be referenced in Appendix G, Figure 43 and Figure 44.

We also created a flowchart of how the design will be coded. In summary, the user turns on the flashlight and shines it at the primary mirror. If they are successful at reflecting the light from the primary mirror to the secondary mirror, the photocell will collect this input. Through the code, MATLAB will then pull up an image. Once finished, the program will end and will restart for the next user. The flowchart can be seen in Figure 11.

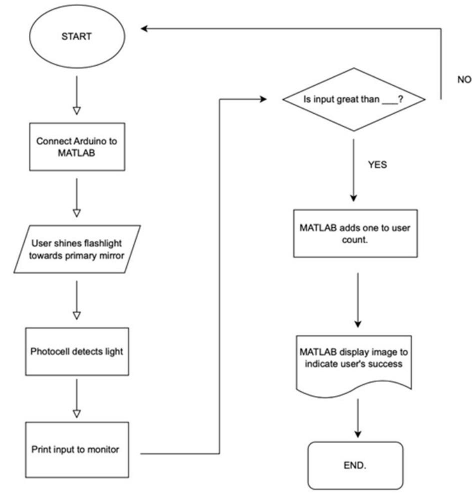

Figure 11. James Webb Telescope Flowchart

After building our prototype, we then began to build the actual design. We created a proof of concept that displayed an image when the light was shined onto the photocell. We also designed the wire diagrams so we could better visualize how the circuit would look like on our actual design. These wire diagrams can be referenced in Appendix F.

For the final 10% we pieced each of the individual parts (base, mirror, box) together and finalized the code to be presented to our clients. After piecing these all together, we painted the design to make the design more visually pleasing to the users and encourage people to interact with the design. We also created a poster to accompany our Webb Telescope design to allow the users to learn more about the function and impact of the real-life telescope. See Appendix G, Figure 47, Figure 48, and Figure 49 for our team's work on piecing the design aspects together.

6.5 EVALUATION

Throughout each step of building the design, we continually tested to see if the design fit all the requirements and objectives for our client. We made sure to double check if the photocell was able to collect the light and if the images would pop up on the screen and de-pixilate. We also aligned the pieces of the design (i.e. base and mirrors) to make sure that they were able to fit together while we worked on each part individually before piecing them together.

For Milestone 5, we also collected data from our peers to understand which areas of our design we should dedicate more time to considering. One takeaway from this feedback was making the design more difficult for the users. We implemented this so if the user does not shine the light to the photocell for a long enough period, then the user will be unsuccessful and will be prompted to try again. If not, then the user will receive a notification that a snapshot was taken and will see a de-pixelated image of a real-life image from the James Webb Telescope.

6.6 INDIVIDUAL CONTRIBUTIONS

For Milestone 1, I was responsible for collecting background research on rovers. This allowed our group to gain inspiration from similar exhibits and activities to incorporate into our final design.

In Milestone 2, I created two designs for consideration. Even though we did not go with either of these designs, it allowed us to compare our other collection of designs to determine the best option for our final design. We could also analyze the concept of each one and see what our team liked or did not like about each of the designs to include in the final design.

Each group member also designed an AutoCAD sketch in Milestone 3 so that we could plan out the layout of the prototype and final design. I built the side view of the design (see Appendix C, Figure 48) and this allowed our team to picture and understand how we would approach building our design. We also worked together on the Rank Order Chart, KTDA, and Problem Statement so that we could determine the best possible design that would solve our client's problem.

I also collected cardboard so that our team would be able to have enough to successfully build our prototype in Milestone 3. This allowed us to build a prototype together that resembled how we would create our final design and see areas in which we could improve on for the final design.

I also designed the wire diagram (see Appendix F) and the caption in Milestone 4 so our team could understand how we would set it up for the final design. This would then make setting it up simple and more manageable when connecting the circuit to our final design. In this milestone, I prepared our evaluation planning table (see Appendix D) so that we could determine in our final design, if we made our planned impact and collected the intended results. I also worked with another team member to cut and prepare the individual pieces of wood to attach for later milestones. See Appendix G, Figure 46 for the cut pieces of wood for the base of the design.

When building the final design in Milestone 5, I was also involved in building the final design. Our work together made the project stable, functional, and visually pleasing for the user. I created the AutoCAD design for laser cutting for the base of the design, the mirror, and the cover for the computer. This allowed all of the electronic parts of the design to be covered to ensure the user's safety. In addition, it made the final design more visually appealing and replicated the actual James Webb Telescope better. I also painted the design to be more visually pleasing. See Appendix G, Figure 52.

PIPER SCHMIDT

7 INTRODUCTION

7.1 PROBLEM STATEMENT

The problem we have been tasked with addressing is the lack of access to interactive and educational STEM content outside of the classroom for middle to high school aged students. The client has requested to aid this problem with a transportable museum exhibit to engage and educate students about various space topics. There are a variety of successful permanent space installations at reputable children's museums around the country which may be seen as inspiration to create a solution. The Franklin Institute has a space exhibit which is very successful in engaging young learners with hands-on activities to reinforce information previously introduced [16].

Our solution will be interactive, as that is the best way to engage students of our target audience, and educational, which we will achieve through an eye-catching model and various colorful graphics to encourage more users to genuinely engage with our product. Our solution will include a game-like activity since that has been proven to be one of the best ways to get students to engage with content [9]. A certain priority should be placed on choosing a unique topic to educate children on, since the target is to reach certain content or methods which are not seen in the classroom. The solution should also adhere to some given constraints, 36" by 28" when set up and portable in a large tote bag, educational content clearly displayed, under $100 to build, under $1000 in value, and safe for all users. The main objectives of the solution are for it to be educational, interactive, safe, and portable.

7.2 STAKEHOLDERS

There are a few prominent groups of stakeholders affected by this problem and invested in the success of a solution. The client and the users are the most important stakeholders in this problem as they are most directly affected by it. However, teachers and other educators who may opt to use the product as a tool to teach students should also be considered as stakeholders. While this solution aims for out-of-class classroom learning, it could also be used to aid classroom learning. A much smaller stakeholder is museum staff and employees who may need to transport and set up the device, if it were to be used as a temporary exhibit in a smaller museum.

The client is an important stakeholder as they have identified the problem, which they have expressed is pressing, sought out a solution, and are finding its solution. The clients' wants and needs were heavily considered to ensure they are happy with the final product, and it addresses their goals. Expanding and understanding their view on the problem is important to our solution. Financially, the client is the most important stakeholder, however, the functionality of the solution does not affect them as closely as it affects the user.

The user is our main priority as the design team. Our target audience is middle to high school aged students. While the client is financially important to the project, the main goal of the project is to aid the user. The user should walk away having gained something educationally, this should be done through an interactive element. The safety of the product is also extremely important to the user since it will most directly affect them.

Teachers and educators should use this solution as an aid in teaching students and other children about various topics. Most ideally, the content of our solution will fall outside of the typical classroom content, so it will be most useful for teachers to employ in their classrooms or at other events. Besides the educational content, the safety of the product is most important to teachers as they will be overseeing the users. They will also have a smaller interest in the transportability and ease of set up of the product as they will have to move the display in and out of their classroom or event space.

Similar to teachers and educators, event staff are invested in the safety and transportability of the product. While they are not responsible for guiding the user through the content, they will be responsible for the set up and transportation of the product. An event, which may use this exhibit, is most invested in the safety of its guests and therefore the safety of this product for its users and those who will be setting up and transporting it.

7.3 SCOPE

This report will cover the engineering design cycle taken to address this problem. The solution was worked through from defining the problem through to evaluation with a client-ready prototype.

8 BACKGROUND

8.1 RESEARCH

To begin understanding our problem and potential solutions, we conducted research into various potential space topics to focus our exhibit on as well as the best ways to teach and engage children, specifically from a museum standpoint. We focused on the best ways to teach and engage children outside of the classroom. Our goal was to identify the best ways to convey the information in our exhibit to children and make it as memorable as possible for them. Starting off, we collected a lot of information about various space topics, like history, rovers, and rockets. However, we decided to focus on a more unique topic, the James Webb Space Telescope.

CHILDREN'S MUSEUMS

Museums use a variety of different techniques to teach children about topics not as frequently seen in the school curriculum. Since many teachers must closely follow the school curriculum there are many topics, specifically new innovation, missed in students' education. There are many successful children's museums around the country which combine interesting and unique topics with hands-on activities to teach children outside of the classroom.

The Franklin Institute has a great example of a children's space museum exhibit. The exhibit, "Wondrous Space", gives information through visual and audio media forms and reinforces it with hands-on activities for children with a variety of interests. The exhibit has many different colorful displays of information as well as audio versions. There is an activity, "Suit up!" which allows students to create a space suit to withstand the conditions on a given planet, they will use information provided about various planets and how to combat their environments for a human. Another activity, "Reach New Heights on Other Worlds", allows the user to see how high they could jump on other planets, testing them on information provided about the difference in gravity on various planets [16]. A good museum exhibit has activities or information which appeals to a variety of different interests.

The best way to engage children in a museum setting is to create an environment where they feel in control of what they are doing so they will take initiative in their learning. This is best done through a game-like activity or technology to encourage the students to engage with the material [9]. This way of presenting and reinforcing new content is what makes museum exhibits most successful in teaching children.

THE JAMES WEBB TELESCOPE

We were drawn to the Webb Telescope since it is a new innovation and likely isn't covered in many museums or classrooms yet. Younger students don't stay as engaged with the news either, so we wanted to use this opportunity to educate them on a relevant topic. This topic is an important new innovation in space. Most of our initial research focused on how to build our own model of the telescope, specifically the various features and their dimensions.

The James Webb Telescope was launched into space on December 25, 2021 and reached its orbit at L2 on January 24, 2022. The telescope studies the history of the universe as it orbits the sun. Unlike the Hubble, it uses infrared light waves rather than ultraviolet light. This allows the telescope to collect and create images through debris and other obstructions, as well as creating images from the past. The main mirror collects the light and channels it off the secondary mirror through a variety of cameras and instruments. The base features an intense sun shade to protect the telescope. The inner technology of the telescope has unprecedented sensitivity to the infrared which allows it to look back in time at the Big Bang and study every phase of the creation of the universe [7].

8.2 ETHICS

To ensure we have worked through our design process ethically we can refer back to the NSPE Code of Ethics for Engineers. To ensure the safety, health, and welfare of the public we will think about the user and how our product can most safely be used. When creating a product for children it is most important to consider the safety of the product in its intended use and unintended use. This means we have spent more time considering any ways the product could be misused, or any use outside of our intention, and making it as safe as possible for the user. As engineers, we will only perform services in the areas of our competence. While we are only students, we have done research into the topics needed to create this product and will not stray from the research we have done. We have acted faithfully for our client, taking all their requests and needs into consideration and making sure they are present in every step of our design [29]. By following the NSPE Code of Ethics for Engineers, we can be most certain we have worked through this project ethically.

8.3 UNIVERSAL DESIGN

Universal design is the design and composition of an environment (or any building, product, or service in that 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 [30]. This was critical throughout our design process since we were not given specifics about the intended user, beyond age. We had to consider the abilities and needs of any student who could be using our product. We may not have been successful in creating a product for everyone, for example a blind student would likely not be able to use our product. However, we considered the needs of a variety of students while staying realistic to our resources and abilities to create this product.

9 METHODOLOGY

9.1 PROBLEM DEFINITION

The problem definition started with the criteria given by the client and culminated in our finalized problem statement. During Milestone 1 we were introduced to the problem, a lack of exposure to certain topics in schools, and the specific needs of the client, an educational portable museum exhibit, that our solution should fulfill. Understanding and expanding on the problem given by the client was our first step. To do this we started by conducting research into various space topics, as specified by the client, as well as how to best engage younger students and what makes a successful museum exhibit. We divided up the research into categories to avoid overlap. We covered rovers, rockets, history, news in space, museum exhibits, and educating young students. By doing this research we were better able to understand the problem. We also worked through an empathy map to better understand the intended user and their specific needs. Using a KTPA chart, we expanded on the problem and constraints given to better understand the potential stakeholders and specifics of the problem. The potential stakeholders include the client, the users (middle to high school students), and the facilitators (teachers and museum employees responsible for set up and transport). After doing this we were able to make our initial problem statement which highlighted the value of an interactive element in engaging young students.

9.2 SOLUTION GENERATION

During the solution generation phase of design we selected a topic, created sketches for potential activities, and met with our mentor to review them against our problem statement. We started off with four topics: rockets, rovers, habitability in space, and the Webb telescope. Ultimately, we decided on the Webb telescope because of its current relevance, the appeal of colorful images it creates, and since it is not likely to be learned about in schools at this point. Moving forward with our topic we each generated a few activity ideas which would be game-like and educational, since our research showed this to be the best way to engage children. We used two different methods for idea generation, vertical and lateral thinking. We felt that lateral thinking was the best way to come up with multiple unique ideas and using vertical thinking was the best way to refine those ideas to fit within our problem outline. I used lateral thinking to generate a matching game from the words "fire" and "game". This first idea can be seen in figure 12.

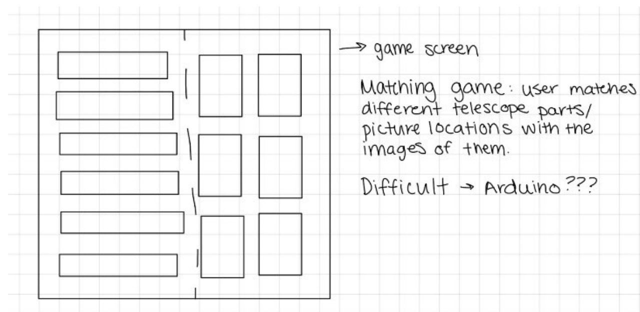

Figure 12 Matching Game Ideation

Then, I used vertical thinking to make some changes to my initial idea. The SCAMPER method allowed me to eliminate overly complicated parts by substituting buttons in place of the user clicking to adhere to our goal of attainability. My second idea can be seen in figure 13.

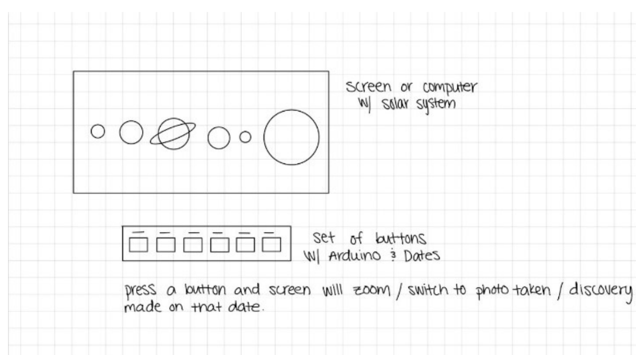

Figure 13 Button Game Ideation

With some solutions generated we decided to revise our problem statement to better fit some changes we made. We wanted to include some of our research to back up our decisions and include the design goals most important to us: interactive, educational, portable, attainable, and safe.

9.3 DECIDING ON A SOLUTION

Once we had created our activity idea sketches, we met with our mentor to review them and decide on one to move forward with. We discussed each activity against the five goals briefly and narrowed down to rank five of our ideas to determine which to proceed with. We used a rank order chart to determine which of our five goals was most important to least important and then assigned them weights based on how they ranked against each other. The rank order chart can be referenced in Appendix L.

We used these weights to create a KTDA chart, seen in Appendix L, which we used to rate each activity on a scale from 1 to 10 in each goal we previously outlined. We then applied the weights and added up the score of each activity. While we had a few activities with similar scores, the Webb Telescope Model came out ranked first with a score of 266.

This aligned with what we felt would be the most interesting and educational of the activities, so we decided to move forward with this. From there we created a new AutoCAD sketch of our activity to proceed with.

9.4 IMPLEMENTATION

To implement our design we created more detailed AutoCAD sketches and built a cardboard prototype which we then recreated with improvements and more durable materials. We divided up the AutoCAD sketches and created a front view, side view, top view, and travel configuration for our design, can be referenced in Appendix C.

To create our cardboard prototype, we scaled down the real telescope roughly 40:1 to have the most accurate model we could. We created the base, primary mirror, and secondary mirror completely out of cardboard. We used this prototyping process to figure out how we were going to model the telescope and attach the different pieces. In the prototype we attached them using wooden dowels and hot glue. The model also shows our initial plan for housing electronics on the back of the primary mirror; however, we later adapted this plan. The cardboard prototype can be seen in photos 1 and 2 of Appendix G.

Along with the cardboard prototype we planned the user interface and electronics to prepare for writing the code. We created a flowchart to outline what we wanted the game to do and set up to begin writing our code. Our flowchart can be seen in figure 14.

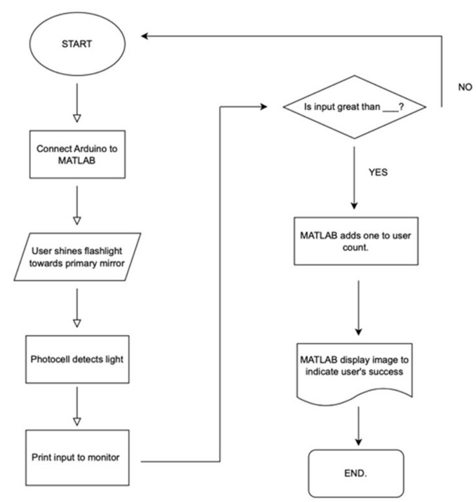

Figure 14 User Interface Flowchart

During Milestone 4 our team started to replace the cardboard prototype with more durable materials to create our final design. To complete our proof of concept and measure the progress of our design process, we first created the primary mirror out of a thin plastic sheet and mirror tiles. We then wired the electronics, see Appendix F, through the primary mirror and tested our initial code.

Our initial code set up the connection between Arduino and Matlab and would bring up an image if the photocell picked up enough light from the flashlight. As a team we were satisfied with this working successfully as our proof of concept since we knew we could improve the code later to make a more complicated and engaging game. Testing our proof of concept can be seen in figure 15.

Figure 15 Testing Proof of Concept

We finished building our prototype by constructing the base out of wood, reinforcing the primary mirror with wood, attaching all the different pieces with wooden dowels, and creating boxes to house the electronics, cover the computer keyboard, and stand the model on. Images of our build process can be seen in photos 5, 6, 7, and 8 in Appendix G.

While continuing the build process through Milestone 5 we were able to update our code to the final which will be detailed later in this report. Our final design is also outlined later in this report. We finished our project in Milestone 6 by painting pieces of it to add to the aesthetics and creating our poster to convey the educational elements of our exhibit.

9.5 EVALUATION

Throughout the building process in Milestones 4, 5, and 6 we continuously tested and made improvements to our code and some of the structural aspects of our model. We evaluated the safety of our design and felt it could be improved so we created boxes to hide all of the electronics from the user. We also covered the keyboard to keep the users' attention on the screen and take away any temptation. After testing our code, we decided to calibrate the photocell to get rid of the impact of the room light and avoid having to change the minimum sensor value in MATLAB if the model was being used in different settings.

We received some important feedback from our peers through the showcase at the end of milestone 5. The biggest piece of feedback we received was that the game may be too easy. This prompted us to implement a timer into the game so the user must completely finish pixelating the image before the time was up. Some said the exhibit wasn't educational enough, but we felt this would be remedied by our poster which was not present at the showcase since it was part of our final 10 percent. These were the biggest improvements we made throughout the design process.

9.6 INDIVIDUAL CONTRIBUTIONS

MILESTONE 1

In Milestone 1, I conducted the research of relevant childrens museum exhibits and topics. I used my research and examples from other exhibits to help guide our group in establishing the values important to our design.

MILESTONE 2

In Milestone 2, I came up with two solution ideas detailed above. I was extremely vocal and involved in our rank order and KTDA process of choosing a solution, frequently reminding my group that attainability is extremely important goal to us.

MILESTONE 3

In Milestone 3, I was the project manager and delegated tasks to my group member and kept us on track with the milestone. I created the travel configuration AutoCAD drawing, see Appendix C. I also created the electronics flowchart and worked on the electronics planning. I took the lead on rewriting our problem statement. I restructured it and implemented changes, like including our design values. During the prototype build I took the lead on scaling down the measurements of our model from the measurements of the telescope and did most of the measurements and outlining.

MILESTONE 4

In Milestone 4, another team member and I created the primary mirror for our initial build. We also worked through the code for our proof of concept and got Arduino and MATLAB communicating to bring up an image when the photocell was receiving light.

RAIN GATRELL

10 INTRODUCTION

10.1 PROBLEM STATEMENT

We are addressing the problem of inaccessible STEM-related content outside of classroom settings for middle and high school students. These students live in rural areas with limited school funding for field trips and new technology or programs. Allowing these students to delve into different STEM concepts is crucial for building a strong interest in STEM-related fields. The client has requested a portable interactive learning experience about space exploration-related topics. Similar to a real museum exhibit, this exhibit should be able to be used by many people, transported to a new location, set up, and used all over again.

The article, "Engagement with an Interactive Museum Exhibit", describes that children engage most with a museum exhibit that has game-like technology and allows the user to feel in control [9]. The Franklin Institute is a reputable children's science museum with many successful exhibits that provide inspiration for this project. Their exhibit, "Wondrous Space", has many interactive activities for visitors to engage with and strengthen their understanding of the topic. The activity, 'Suit Up!' allows users to design their own space suit that can withstand the elements of their destination. A game like this allows the user to feel in control as they are making their own decisions. Since the user is creating a suit to withstand the conditions of different destinations, the game is testing their understanding of different environments in space. This creates a knowledge recall aspect that could be incorporated into this client's final product. The Franklin Institute is so successful because it creates exhibits with many different activities like this that test the user on different content presented [16].

There are a variety of museum exhibits and in-class activities to teach students about topics such as space exploration, however there are limited portable designs. One applicable example is a school bus in India that was converted into a traveling museum and can be used as inspiration for a portable exhibit. While this is a much larger scale than our client's request, this museum keeps more delicate items in cases highlighting the importance of durability and safety. They also have activity sheets and handouts, which is a form of recall for the user, seen in many different museums [21].

The client provided a few constraints: 36" by 28" when set up, transportable in a specific configuration, containing educational text with titles and other important information, safe for user and transport, and total cost under $1000. Considering initial information, the solution should have educational content that is clearly presented to a user on a poster board with plenty of visual and written guides such as captions. The solution should also have a game-like activity that allows the user to feel in control and promotes engagement which will be measured through tracking user interaction. There will also be a recall element to solidify the user's understanding, and protection measures will be taken to ensure durability and safety by hiding all electronic components and wires.

10.2 STAKEHOLDERS

This project affects a wide range of stakeholders, with varying impacts on each. The primary stakeholders are the ones more directly involved, first being the client who we are addressing this problem for, and the second being the user whom the project is made to educate. Because of the environment the users are in, the projects' effects spread more widely. Namely to other educators and teachers at their schools, as well as any friends or family members that may be interested. While our project aims to expand STEM interests outside of the classroom, it can also be utilized by teachers in classroom settings.

Our main stakeholder is our client, who has presented the problem to us and is requesting a solution. The clients' needs were always of top importance when making decisions for this project. Though the clients' requirements came first, the user was always considered when making any part of the project, since they were the ones directly interacting with it.

A significant stakeholder was the user. Since the age range was middle to high school students, we had to ensure that our project would be engaging and fun, but not too childish. Because we were addressing a large age range, we needed the exhibit to be fun to play, not too easy, but also not too difficult. We also wanted to ensure that the kids didn't feel like they were having information shoved at them. Instead, our desire was for the user to want to learn for the sake of completing the game. Some other factors were the safety of the user since they were most directly affected. Because of this we thoroughly evaluated and adjusted our project for the safety of the user during the design process.

Indirect stakeholders include teachers and educators. Though our project is supposed to be an out-of-classroom exhibit, because of its easy setup and low cost, it can easily be implemented into a classroom setting for further STEM engagement. Because of the exhibits' interactive and visual elements, it could easily accompany a lesson plan with much ease. Because of the exhibit's safety features, teachers and educators could introduce it to their classes without much worry.

10.3 SCOPE

This technical report aims to cover the engineering design process for the creation of this project per the clients'] restraints and requirements.

11 BACKGROUND

This section seeks to contextualize our project within the broader landscape of interactive education and STEM, with a greater understanding of the thoughts and actions behind our project.

11.1 RESEARCH

Our initial research began with four topics all relevant to the exhibit's theme of space exploration. These topics were rovers, rockets, successful exhibits, and the history of space travel. We did this so we could get a broad understanding of the theme and what the client might be looking for. This initial research along with some general background research questions helped guide us along to our initial ideas for our exhibit.

While doing research and generating ideas we were always considerate of our design constraints and requirements. In doing so we were able to think more realistically about what would and could not be done in the amount of time we had. This also allowed us to narrow down our ideas and initial concepts better. Our goal was to create an interactive STEM exhibit that was cheap, portable, safe, and easy to use.

We decided to do our project on the James Webb Space Telescope. Because this was a focus on a single subject instead of a broad one, the Webb Telescope presented a unique element that not many other project groups were likely to do. Not only that, but not many students were likely to learn about it in school, despite its many contributions to science and its interesting and complex design.

We began doing more research on the James Webb Telescope to better understand and enhance our designs. On the James Webb Space Telescope website, we were able to find loads of useful information regarding the design, use, and impact of the telescope. There we were able to find pictures of the initial build of the telescope, showing the design and structure of the mirrors. That along with a page dedicated to educational content that was related to or made for educators to teach about the Webb Telescope.

This is where we found many outlines and instructions for how to make our very own model of the Webb Telescope. This along with inspiration from the games and educational videos helped us generate ideas for the interactive elements of our exhibit. Many of the games featured interactive elements teaching of the different parts of the Webb Telescope in a digestible manner. We wanted to integrate this easy teaching pattern into our exhibit.

11.2 ETHICS

To ensure an ethical design process and execution, we frequently referred to the NSPE Code of Ethics for Engineers. We aim to hold a high standard for the safety and welfare of our users. To ensure that there was no threat of injury, we made adjustments to our initial design ideas. Since we are dealing with younger users, we needed to ensure that there was no way that our project would be misused in a way that could harm the user or others. For example, we switched to using a flashlight connected to the project instead of a laser pointer that could be taken or flashed in someone's eyes. This also falls under the standards and requirements placed upon us by the client.

11.3 UNIVERSAL DESIGN

Universal design is a design that is created with the intention to be usable by all. This is without limitation or interference due to one's identification, orientation, disability, or differences. A universal design does not require a special adaptation, which may separate users, but instead has an accommodating design that is suitable for all who wish to use it. Universal design is an important aspect of the design process. By limiting the usability of your design, you not only limit the function of it but also your clientele. When starting our design process, we constantly had this in mind. Creating an exhibit that not only was fun to use but also accessible to all was the fundamental basis of our design implementation. For example, we gave many different sources of direction for the user to follow.

12 METHODOLOGY

12.1 PROBLEM DEFINITON

To start our research for this project we first took into account the request from the client and whether our initial background research was within the parameters of their requests. The idea of creating a museum exhibit was a very new concept, so to form a solid understanding of what was really being asked of us, we made sure to thoroughly review the parameters set by the client. The topic of the exhibit was space exploration, which at first can seem very broad and daunting. We started our research by splitting into four sections, with their own unique sub-sections for further analysis. These sections were rovers, rockets, successful museum exhibits, and the history of space travel. All of these subjects were very broad, but in doing so we were able to get a wide understanding of the exhibits' goals.

12.2 SOLUTION GENERATION

When working to finalize any ideas we had generated for our project, we listed out each possible subject that we would be interested in delving into. These final topics included rockets, rovers, the Webb Telescope, and habitability in space. When discussing these, we took into account how relevant they were to our project theme and how relevant they were to our users. Though rockets and rovers seemed like a fun idea, we had concerns about other groups doing similar topics and having overlap. Habitability in space seemed more current and possibly applicable to their future, but difficult to make into a fun and engaging game. We decided on the Webb Telescope because it is a unique topic and not many children would have learned about it in school. Not only that, but introduces a type of technology that many kids would not be familiar with.

The next step of our idea process was to create sketches of our project and to meet with our mentor to gain feedback on any initial ideas we had generated. My first designs were very similar in nature, just with different approaches. I used ideas from old games and toys from childhood to be the base of both designs. For the first design, I thought of old hunting arcade games, which used a small light signal when the 'trigger' was pulled, allowing the user to aim and shoot. Later designs of games like these, and in modern remotes and things like the Nintendo Wii use more advanced versions of this to get input from the user. My first design was a very simplified version of this featuring a model of the Webb Telescope and a light source. When the button was pressed on the light it displayed an image taken from the actual Webb Telescope.

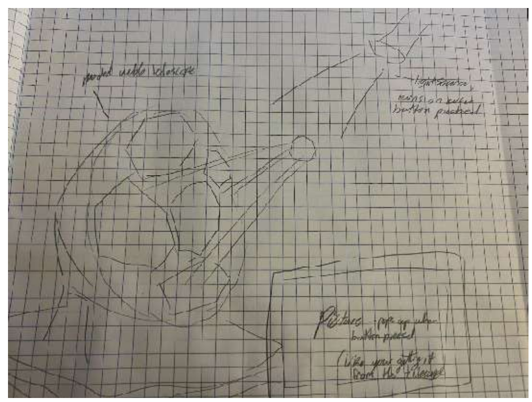

Figure 16 Design Generated Idea #1

My second design was much simpler and took inspiration from a View-Master, a toy very popular in the 90's. The toy itself just has many photos on a circular disk, which when the side button is pressed, flips through a photo at a time. Since we wanted to see images from the telescope, this was just an easy non-electronic way to display them. The design created just had the eyepiece from the View master on a model of the Webb telescope, but not much else.

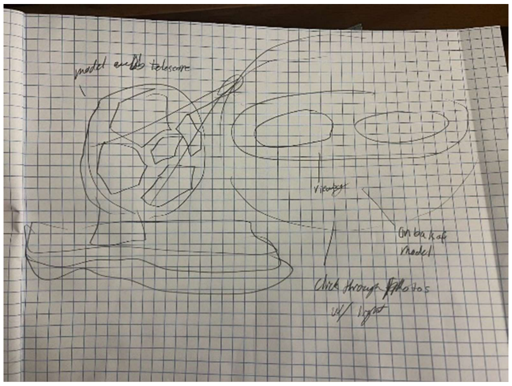

Figure 17 Design Generated Idea #2

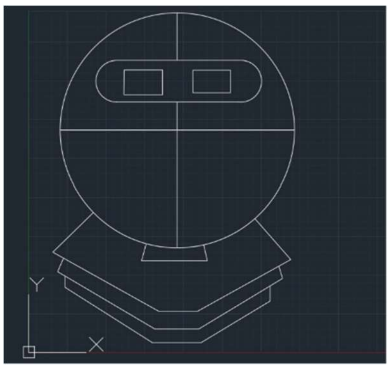

Figure 18 Final Sketch of Design #2

I decided that my second design was the most unique, and had more room to add on, so when making decisions on which idea to finalize, my second generated idea was considered.

12.3 DECIDING ON A SOLUTION

After generating our first set of ideas, we decided to revise our problem statement and weigh the importance of each of our goals: durability, attainability, educational, interactive elements, and portability. We decided their level of importance in that exact order, from most to least. We decided that the safety of the user was the top priority, since this most directly affected the user, and the portability was least important since it affected the user the least amount. We did this via a Rank Order chart.

When deciding which design to choose, we used a KTDA chart, which implements the importance of each separate goal, such as durability and portability. This way each was ranked according to how important we had previously set them to be on the rank order chart. This combined with how well we thought each separate design faired against each goal created each design's individual score. After we ranked each, we ended up choosing the model telescope design with a photocell because it scored the highest overall.

12.4 IMPLEMENTATION

For the initial creation of our first prototype, we started off with AutoCAD drawings of each angle of our model telescope. To do this, we needed rough measurements of the telescope itself. To find this, we went to the James Webb Space Telescope website. Here they have many different instructions and model telescope cutouts, along with some of the base measurements for the actual telescope. These online model instructions along with the base measurements became the basis for the start of our first prototype design. We first scaled down the base measurements to 1:40, much like those we saw on the website. Then we used the cutouts of model builds to be the basis of how we would create and design our own with different measurements. After creating our AutoCAD drawings we started on our first physical prototype out of cardboard.

12.5 EVALUATION

When creating our design we had different ideas on how to get our mirrors to fully work, as well as how to prevent the photocell from simply getting light straight from the flashlight. Some of these included putting the photocell back slightly, and in the dark, that way it wouldn't pick up any outside light, and then be more sensitive when it picked up the refracted light. Creating a good curve that was also sturdy enough to hold the mirrors was a big hassle since it was hard to find material that would bend and curve, but was not at all flimsy. In the end, we used a combination of flimsy material for the base and then thin wood to support the back. For the final project, instead of making the base diamond sheets separate, like the actual Webb Telescope, we opted to glue them together. This was to ensure that the project was sturdy and didn't have any pinch points that someone could possibly get hurt on. Because of its cardboard frame, it was very flimsy, and there was a lot of concern about it breaking. Having this initial model allowed us to assess some potential problems, such as having a bigger box behind the mirrors to hold the electrical components as well as a box on the bottom for a base and to hide any wiring.

12.6 INDIVIDUAL CONTRIBUTIONS

In Milestone 1 I conducted research on Rockets and how they work. This was a part of the beginning process of figuring out what we wanted to base our project on. My research showed the potential benefits and disadvantages of doing rockets for our project, and eventually led to the conclusion to not go with rockets.

For Milestone 2 I created base and final sketches for potential ideas surrounding a Webb Telescope project. My initial ideas involved models of the Webb Telescope, one that showed an image when a button was pressed, and another that showed pictures through a lens. My final AutoCAD drawing featured the idea of showing a picture through a lens. Though my design was not chosen, it was a close second and helped give more ideas on how to improve our final design.

In Milestone 3 I helped a lot with the build of the model telescope out of cardboard. I often checked the design of the actual Webb Telescope to ensure that we were being accurate in our build. I also provided AutoCAD sketches for our design from the top view and helped create the flowchart for our coding. I provided the wooden dowels as well as most of the cardboard used for our model.

For Milestone 4 I helped with the evaluation planning portion. I also provided photos from the Webb Telescope to use in our programming. Finally, I helped to cut out the boards for the base in our final design, using wood I obtained from Home Depot.

Milestone 5 we started to finalize the build of our project. I helped to construct the base and sort the pieces to be aligned with one another. Once the base was glued and drilled together, I sanded down the sides so that it had a more even and neat look.

13 FINAL DESIGN

Our final design is a smaller-scale replica of NASA's Webb Telescope. We scaled our model down 40:1 from the original and made a few minor design changes to improve user experience and safety. The base of our design to replicate the base and sun shield of the telescope was cut from wooden boards. The base is five layers, 21.5" by 14", and are cut into rhombuses with flat edges at the front and back. The five boards are wood glued and nailed together. The base is painted silver to replicate the look of the sun shield. Our model also has a main mirror (Figure 19) attached to the secondary mirror. The main mirror is created on a piece of thin plastic and shaped into a slight cone, 6.5" in diameter. On the plastic we glued three rows of 1-inch hexagonal mirrored tiles, leaving the center open to attach the photocell. This strays slightly from the main design which has only two rows since the mirrored tiles we used were too small.

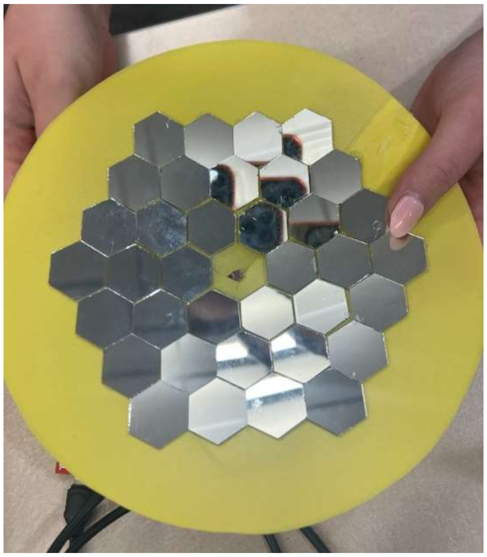

Figure 19. The Primary Mirror

The primary is reinforced with a thin wooden material which was scored to create the cone shape and glued onto the back of the plastic. The secondary mirror was created with just one mirror tile attached to a small piece of wood as a base. The primary mirror is attached to the secondary mirror (Fig. 20) using wooden dowels and small holes in the bases of the primary and secondary mirrors.

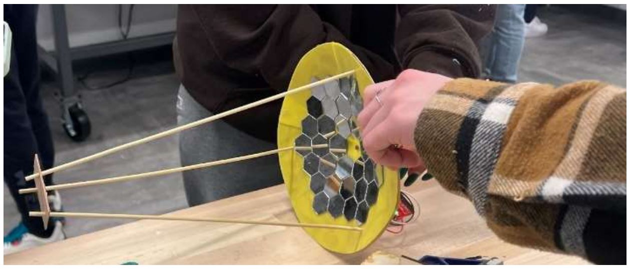

Figure 20. The secondary mirror attached to the primary mirror

The secondary mirror sits 8 inches away from the primary mirror. Attached behind the primary mirror is a laser-cut wooden box (Fig. 21), 5" x 3" x 1.5", to house the breadboard for the photocell. The primary mirror is attached to the box with glue and the box sits on top of the base. The base has a hole cut in the center, 1-inch in diameter, to run the wires from this part of the circuit to the breadboard which is housed outside of the model. The box behind the primary mirror also has a wooden dowel, ½ inch in diameter, glued into the inside and sitting inside the hole in the base to keep the primary mirror centered on the model while keeping easy access to the electronics.

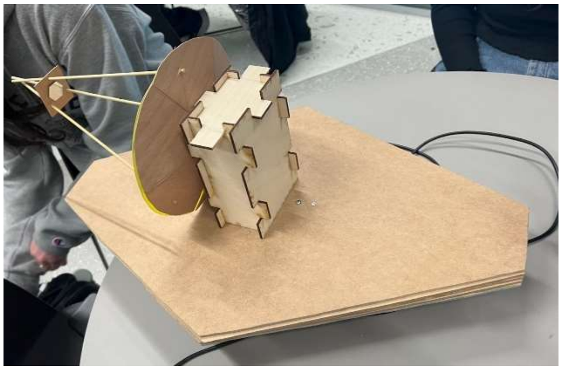

Figure 21. Backview of Design

The base of the model sits on top of a stand, 10” x 10” x 2”, (Fig. 22) to prop up the model off the table and be able to run the electronics out under the model. Two sides of the base have cut outs to allow the wires to run out from under the model. The base is screwed into the stand.

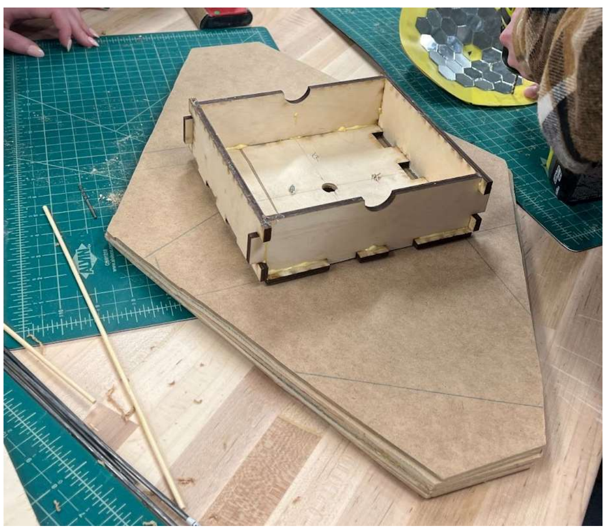

Figure 22. The Underside of the Base

13.1 EXHIBIT OVERVIEW

Our exhibit features our model of the telescope with flashlight attached, a laptop to run the game on, a laptop cover to protect it from users, and an informational trifold (Fig. 23).

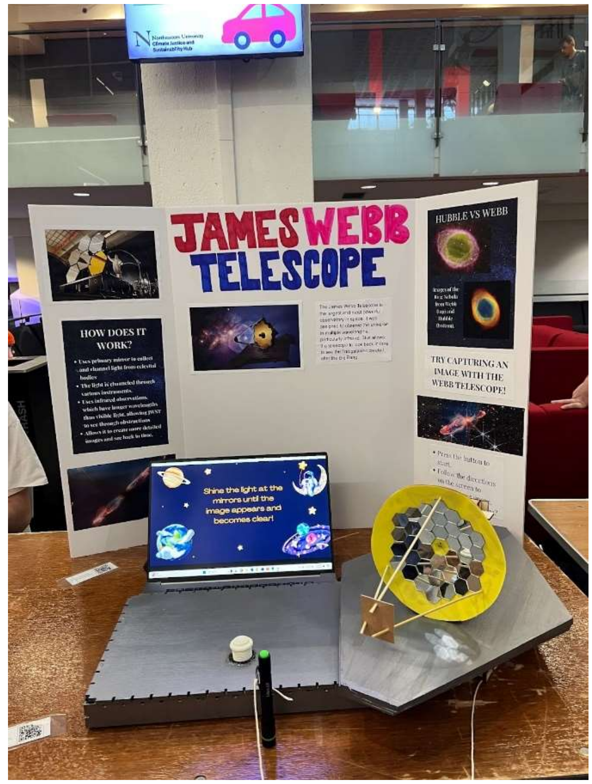

Figure 23. The final exhibit at the exposition

The trifold in the back shows images of the telescope and some images the telescope took to convey the impressive size and precision of the telescope. There are also some informational captions about how the telescope works. The laptop screen displays the game for the user. The cover holds the button to reset and start the game, while also protecting the keyboard from users. The cover is laser-cut from wood and wood glued together, then painted silver to improve aesthetics. The final component of the exhibit is the model as described previously with the flashlight attached for the game.

13.2 USER EXPERIENCE

The user experience is visualized in the flowchart shown in Figure 22. A message appears on the display instructing the user to shine the flashlight onto the primary mirror. If the user shines the flashlight onto the mirror and successfully has it reflect onto the photocell, a pixelated image will appear on the display. If the user continues to successfully shine the light, the image will unpixelate and become clearer. If the user does this within the five second time limit, a “snapshot” will be taken, and the user will be informed that they were successful. If they do not complete the task in five seconds, they will be shown a “time’s up” message. Once either message is shown, the user can click the button to restart the game and play again.

We kept the user interaction element relatively simple so it can be used by a diverse age range as we wanted to consider universal design in our product. The poster board also contains interesting information on the James Webb Telescope, so if our user is unable to participate in the interactive portion of our product, they can still learn something by reading the text blurbs and looking at the images.

13.3 FUNCTIONAL COMPONENTS

We used a folder to form the rounded primary mirror to replicate the actual Webb Telescope. This allowed the design to be angled enough so that the light from the flashlight would be reflected off of the primary mirror, to the secondary mirror, and then finally to the photocell. Without the folder, we would not have had the flexibility to accomplish this reflection of the light for the design to function properly. In addition, the wooden dowels provided support for the secondary mirror to reflect the light from the primary mirror. This allowed enough support for the reflection and durability when the users shined the light at the primary mirror. See Figure 24 of the primary mirror of the design.

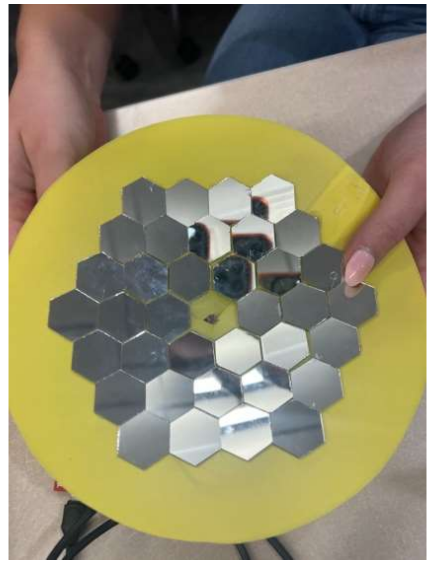

Figure 24. Primary Mirror

We also laser cut the box over the computer to fit well so that the button was positioned well for the user and the electronic components could be easily and safely stored away. The design of this laser cut object allowed our team to prioritize the user’s safety while also ensuring that the button could be properly supported for the user and to send the inputs to the program. See Figure 25 and Figure 26 for the layout of the computer box.

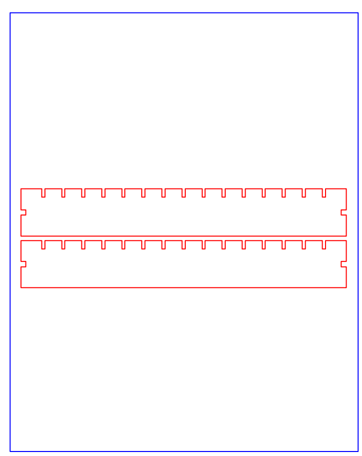

Figure 25. AutoCAD drawing of the side pieces of the computer cover

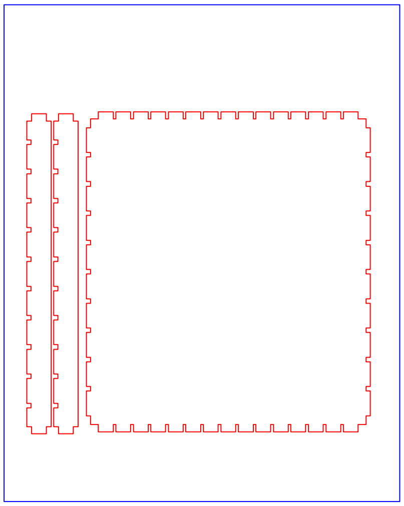

Figure 26. AutoCAD drawing of the side and top pieces for the computer cover

The base of the design also contributed towards the functionality of the design. This is because it allows the user to be at a better height to shine the light at the primary mirror. It also allowed our team more space to store electronic components to store away from the user and prevent any injuries. See Figure 27 for the layout of the base of the design.

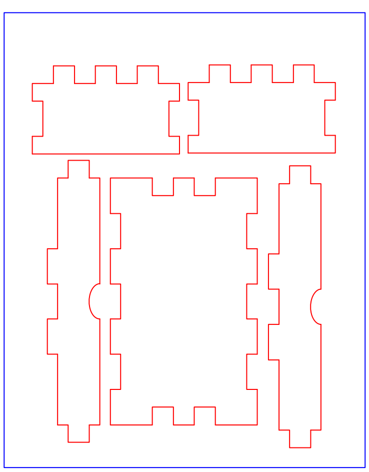

Figure 27. AutoCAD drawing of the backboard for the mirror

Finally, the backboard of the primary mirror played an important role of supporting the primary and secondary mirrors. Without this backboard, we would not have been able to properly support this crucial aspect of our design. The mirror was where the program would receive any input, and without it, the program would not have received any accurate inputs. See Figure 28 for the layout of the backboard for the mirrors.

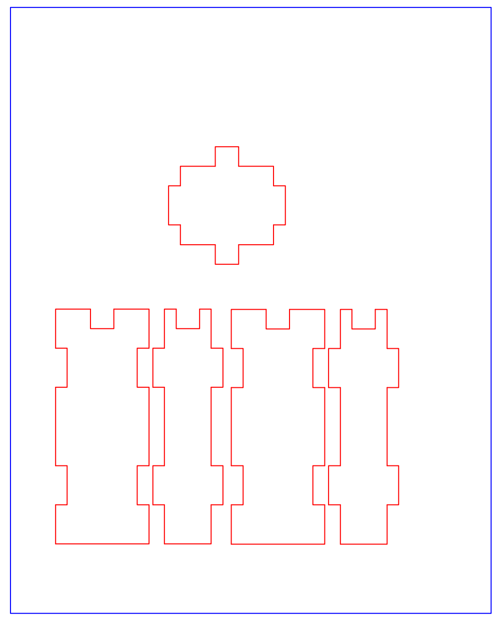

Figure 28. AutoCAD drawing of the base of the computer cover

13.4 ELECTRONICS/SOFTWARE

Our model required a photocell and button inputs and MATLAB outputs. We used one RedBoard with two breadboards, one for each element. One circuit was in the model with the photocell and required a 10k Ohm resistor and multiple wires. The other circuit was underneath the keyboard cover with the button and required a 330 Ohm resistor and multiple wires. The wiring for both of these circuits can be seen in Appendix F.

This RedBoard is connected to the laptop through a USB cable and sends MATLAB the photocell and button inputs through Arduino. MATLAB communicates with Arduino and processes these inputs and accordingly displays images. The button acts as a start/restart button and displays the starting title screen when pressed. Arduino sends MATLAB the photocell values and depending on how high the value is, MATLAB will display an image and slowly pixelate it. The flowchart describing user input and MATLAB output can be seen in Figure 29. The fully commented Arduino and MATLAB code can be seen in Appendix E.

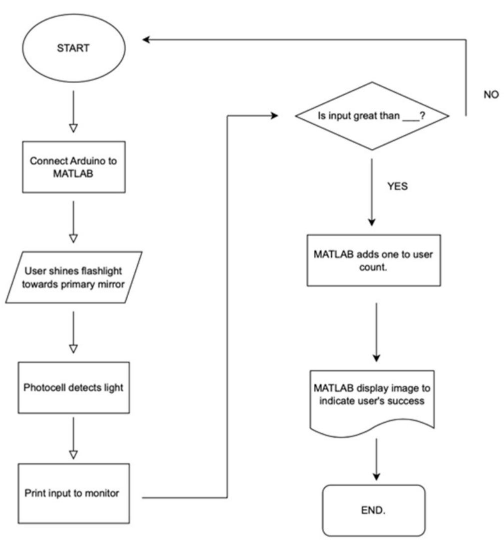

Figure 29. Flowchart for program and user experience

14 RESULTS

14.1 PHYSICAL CHARACTERISTICS

The model withstood our two-hour exposition without any damage. All wires and electronics remained hidden and were intact throughout the entire exposition. Many users positively commented on the aesthetic elements of the exhibit, specifically the telescope.

14.2 EXHIBIT MEASUREMENTS

The exhibit measured 33 in by 25 in. The model telescope itself measured 13” wide by 21” deep.

14.3 EXPO RESULTS

The function of our exhibit was tested at the showcase. We had to restart our code 9 times because of an irregular error message in the MATLAB portion of the code or a period of five minutes without any interaction. The set up of our exhibit took two and a half minutes and the breakdown took two minutes. We did not see many intended users due to room set-up and timeslot. However, many of our peers interacted with the exhibit.

14.4 EDUCATIONAL TESTING RESULTS

Through the peer feedback form, we received critical feedback. Of the responses that we received, 100% replied “yes” to the question, “would you interact with this exhibit again.” 80% of respondents replied “yes” to finding the exhibit educational. We received a variety of responses to “how difficult as it to accomplish the exhibit’s goal?” 20% replied that the exhibit was “too easy”, 40% said that it was “somewhat easy”, 20% said that it was “average”, and 20% said that the exhibit was “too difficult.” Our final question was “would you recommend this exhibit to a friend” and 100% of respondents replied “yes.”

Our team did not collect user interaction data electronically, but we were observant during the time period for the exposition. During this time, we noticed that many of the users did not read the James Webb Telescope information on our poster board. Instead, the users immediately began to interact with the design. After completing the activity, they left without gaining further insight into the real-life telescope, which was located on our team’s posterboard.

14.5 ENJOYMENT TESTING RESULTS

Through the peer feedback form, 100% of users stated that they would use the exhibit again. During the exhibit showcase we had many repeat users. Many users showed interest in the functional aspects of the project, and visible excitement when completing the task successfully. No users showed any difficulty or frustration with completing the task, though not every user was successful at the first try.

14.6 USABILITY

Almost 100% of users during the exposition asked our team how to interact with our exhibit instead of reading the instructions on the screen and poster board. After completing the activity once, instructions were no longer needed.

AASHNA SAHANI

15 DISCUSSION/ANALYSIS

After completing our design and presenting it at the exposition, we have determined that our exhibit was successful and meets all the requirements given by our client, along with some additional group and course goals. These goals and constraints were outlined in our problem statement, which we kept in mind and made sure to prioritize during the design process.

15.1 EASILY MEASURED GOALS AND REQUIREMENTS

The most easily measured client and course goals of this project are the size, transport configuration, cost/value, SparkFun components, and laser cut parts. These are all very physical and tangible goals to measure so it is easier to determine whether we were successful at them.

The size restrictions of this project are that the entirety of the exhibit must fit onto a 36” wide by 28” deep tabletop. Our exhibit fit in this space perfectly as our model telescope was about 13” wide by 21” deep, and our only other elements were a laptop and upright poster board, which did not take up much space. There was also a size constraint when it came to the transport configuration as our entire exhibit had to fit in a large tote bag. The main parts of our exhibit, when in transport configuration, were the poster, telescope mirrors, telescope base, laptop, and keyboard box. These elements all fit in the bag and created a smooth set up due to the limited number of parts.

We successfully met the cost and value constraints as well. As seen in our bill of materials, our final cost for our project was $84.65, which is under the course limit of $100. Our client’s value constraint was $1000, and our final value was also far below the budget, as it was $285.

Two of our course goals were to use two interactive SparkFun elements as well as at least one 3D printed, CNC milled, or laser curt part. Our main SparkFun element was the photocell in the center of the primary mirror of the model telescope which recorded the user input of amount of light. Our second element was our restart button. We also laser cut multiple boxes to keep our electronics in. We met this course goal as we had all the required elements as described above.

15.2 HARDER TO MEASURE GOALS AND REQUIREMENTS

The harder to measure client and course goals are how educational, interactive/game-like, safe, and durable the final product is. These goals are more dependent on the user’s opinion and experience and require a slightly longer testing time to properly measure.

Measuring the success of the educational aspects of our exhibit is difficult since it relies on user feedback. During our gallery walk, we created a form that asked our peers if they thought our exhibit was educational. About 80% of responses said it was, but we decided to add an informational poster board to include additional information and clarify any questions about the exhibit. Under the goal of educational, there is a constraint that there must be education text explaining the concept which was accomplished through our poster as well. However, during the exposition, most users, especially children, did not pay attention to the information on the poster. I would conclude that we were unsuccessful at this objective since even though we had informational elements in our exhibit, most users didn't interact with them. We also did not collect any numerical data through a recall quiz or feedback form to prove that they did.

We used the same form to measure the engagement and interactivity of our exhibit. 100% of respondents said they would interact with our exhibit again and would recommend it to a friend, concluding that we were successful at this objective. We also added a five second time limit to our exhibit which increased the game-like aspect of it. By observing users at the exposition, we also noticed that people often played multiple times if they had lost previously or if they were with a friend, suggesting that our exhibit was also competitive. We did lack numerical data in this category as well, making it more difficult to prove success since our conclusions were mostly made based on our observations.

Safety and durability were the most difficult to measure without directly testing our products with our users. We created multiple boxes to hide any electrical parts from the user and there were no safety concerns when observing our users. The exhibit also lasted the entire exposition and was in the same condition as in the beginning, meaning it met our durability goal. It could be improved with some stronger materials and reinforcement, however for our short-term purposes I believe it was successful.

16 CONCLUSION

Our client requested that our team create a portable museum exhibit that teaches educationally underprivileged middle and high school students about the topic of space exploration. They wanted an educational and interactive exhibit that would provide the students with a similar experience to going to a real museum.

Our client also gave specific objectives and constraints that the final design had to meet. These requirements included that the exhibit must fit on a 36” by 28” tabletop and must fit inside a large bag for transportation. The product also had to cost our client less than $1000 and had to be safe during transportation and use.

Our team decided to create an exhibit on the topic of the James Webb Telescope due to its uniqueness as a topic, and its visual appeal. With this topic and our main goals in mind, we were able to decide on the Model Telescope design as it best fits our goals of educational, interactive, portable, safe/durable, and attainable.

This solution is essentially a miniature simplified version of the actual Webb Telescope. Physically, it has most of the features of the actual telescope such as the layered base, primary and secondary mirrors, and a sensor. The user is supposed to shine a flashlight at the primary mirror, and if they successfully reflect the light off the secondary mirror on to the photocell in the center of the mirror, a pixelated image, taken by the Webb Telescope, will appear on the display. As the user continues to shine light at the mirrors, the image will unpixelate, giving the user a sense of how the Webb Telescope collects light to create images.

I believe that our final product was successful as it met all the requirements set by our client. It fell slightly short in educational, but still had the required aspects, such as informational text. It met all the size and price constraints and was easily transportable. From our peers’ reviews, our design was also very interactive and engaging, however it felt too easy.

From these suggestions, we adjusted our code to add a time limit to the activity to improve the game-like aspect of our final design. While we did not collect numerical data on our criteria of game-like design, we concluded that this made our exhibit more fun and competitive as users at the exposition would play multiple times if they ran out of time and were not successful the first time. Through the evaluation portion of our design process, we also decided to add a restart button to create a smoother user experience.

Our design process was successful in undertaking our client’s problem. By conducting research and formulating our problem statement to begin, we had a good understanding of what our final solution needed to be successful. Our solution generation gave us a broad range of ideas to consider and eventually systematically decide on through our use of a rank order and Kepner Tregoe Decision Analysis chart. Our cardboard prototype was very helpful in identifying areas that required additional work and made the transition to our final design much smoother. For next time, we will prioritize our evaluation and feedback plan more so we can use numerical data to make changes to our design and justify our success in some categories.

As this product is to be used at schools, it can potentially benefit teachers and educators by providing them with an additional teaching aid. The main user remains the same, middle, and high school students, yet the product’s intended use can change. The main concerns of our product are how accessible it is as well as how well we

educate the students since we are working with an
educationally underprivileged group of students.

17 RECOMMENDATIONS

17.1 DATA COLLECTION

While we collected feedback from our peers, we failed to collect numerical data during the exposition. We did not include any sort of quiz, form, or counter in our code to measure the number of users that interacted with our exhibit, and how they felt after interacting with our exhibit.

Specifically, we did not collect any data from the exposition on the educational content nor on the engagement and game-like aspect of our exhibit. This hindered us from being able to measure the success rate of our exhibit and how to improve our exhibit in those areas in the future. We were unable to conclude whether our poster taught the user additional information and whether they enjoyed using interacting with our exhibit. We noted mental observations as people interacted with our exhibit during the exposition which gave us the understanding that most users did enjoy our exhibit, however there is no way to prove this without some sort of data.

Incorporating a quiz regarding facts about the Webb Telescope would have provided us with the number of total users along with a sense of how much they learned based on what percentage of questions they get right. A feedback form would gather similar data; however, it would not be as well integrated into the exhibit as a quiz.

17.2 PHYSICAL IMPROVEMENTS

Our model greatly depended on its physical appearance as it is meant to be a miniature replica of the real James Webb Telescope, however there were some areas where it fell short. The main area we struggled with was our three boxes that we laser cut. These boxes included the base of the telescope, the housing for the electronics, and the laptop keyboard cover.

The boxes did not fit together very well due to the cutout pattern and the laser cutting layout, so some dimension resizing would have helped. The keyboard cover was also slightly too small to comfortably fit the rest of the electronics underneath it, so creating a slightly larger box would have been beneficial.

These recommendations only affect the aesthetics of the exhibit, not so much the function, so they are easier to accomplish. A display will also most likely replace the laptop in the long-term solution, so the keyboard cover would not be necessary.

17.3 EASE OF UNDERSTANDING

Another area where our exhibit fell short was how intuitive our exhibit was. During our in-class gallery walk, most of our peers had to ask us how to interact and use our model telescope, since its function was not very clear just by looking at it. We tried to improve this by adding some simple instructions on our display along with on our poster board, however even at the exposition, we had to verbally explain our exhibit to most users.

This could be improved by adding slightly more detailed instructions on the display, as most users did not read the entirety of the poster board. An audio guide also could have been beneficial so users could learn the instructions and play the game simultaneously.

Once our users understood how to play our game, they were able to interact with it smoothly, however since this exhibit is meant to stand alone, it is important that it is intuitive to its users.

17.4 PHOTOCELL DETECTION

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18 LESSONS LEARNED

18.1 CONTRIBUTIONS

I helped create the main model and transition from our cardboard prototype to our final model. I mainly worked on the primary and secondary mirrors and the attachment of some elements. I worked on attaching the hexagonal mirrors to the flexible plastic backing. I also helped to make the plastic form a conical shape and reinforced it with a flexible and hatched wooden backing.

There were also some issues with our laser cut boxes, so I assisted in cutting some of the parts down so the sides all fit together. I also created a hole in one of our boxes for our wiring. I assisted with the nailing and glueing of our base layers and boxes. I also assisted on most of the wiring and attaching the electronics, including the button, breadboard, and RedBoard, to their respective boxes.

I also wrote most of the code, especially after the proof of concept. The main changes I made to the code were changes to the visual elements of the display, as well as the timer, pixelation, and button. This code can be found in appendix E.

I changed the MATLAB figure to be full screen as it originally only populated a small portion of the display. I also created and added the images that acted as title and description screens, which can be seen in appendix H. Lastly, I added more images taken by the Webb Telescope to the MATLAB image folder.

I also added a timer element to the code so that the user only had five seconds to win the game. This is something we had been trying to achieve before, but I had some issues with getting a value from the datetime function in MATLAB. This added the game-like element to our exhibit since the user now had a way to win or lose the game. I added a "Times-Up" screen, as seen in figure ___, to appear if the user ran out of time and lost the game.

I also changed the code so the image would stop pixelating if the photocell was not picking up values that were high enough. This also added to the game-like element of the exhibit since the user had to continuously shine the light correctly instead of shining it only once to win. I had to add additional if-else statements to stop the image from pixelating once the pixels were small enough that the image was clear to avoid any errors. I added a "Nice Job" screen as seen in figure ___, to appear if the image was clear and the user was under the time limit. I also made it seem like the display was taking a snapshot of the image by switching from the image to a black screen and back to the image.

Lastly, I integrated a start/restart button into our code. I added an if-else statement to the Arduino code to print a message if the button was pressed. I had MATLAB scan for this message and if it found it, it would return to the start screen, as shown in figure ___.

18.2 RESOURCES

Our group was under the given budget of $100 as our final cost was $84.65. We were also under the We acquired most of our materials from FYELIC, our SparkFun kits, or Professor O'Connell, so most of our cost came from the wood, mirrors, paint, and poster we had to purchase. I personally purchased the hexagonal mirror tiles and some wood which cost me $27. My laptop was also used as the display and was used throughout the entire project for testing purposes. I personally also acquired the second breadboard we used, along with the plastic used for the backing of the primary mirror.

I spent 37.5 working on this project from Milestone 1 through 6.

This project has made me understand the importance of resource management and how to use it as a tool. Creating a bill of materials early on made it easier to get materials on time since we had to order some things online. Using a Gantt chart was also useful in identifying the tasks we had to complete each week. Structuring our time like this was helpful since in this big project there were a lot of smaller tasks to finish. I will probably focus on the timeline aspect of the Gantt chart more in the future and follow the dates set in it instead of only treating it as a to do list.

18.3 REFLECTIONS ON LEARNING

I learned about the importance of the design process. I was often eager to jump straight into the building of the final prototype instead of going through the research, prototyping, and evaluation planning steps. I have never done a project that required going through the entire design process so some of it was relatively new to me as well. After getting further into the project, around Milestone 5 when we were creating our final design, I realized how important it was to have a plan in place. We were able to continue to improve our project as we came across issues by using our research and reflecting on our evaluation plan. Our cardboard prototype also helped us identify major problems early on. I also gained some building skills as a large portion of our exhibit relied heavily on the accuracy of the physical structure of our model.

Presenting our team's status was also something that was new to me. I found it helpful to be able to see what other groups were working on and where they were in their design process. It was also helpful to summarize our own work to know what we still needed to work on.

I had to teach myself a lot of the code used in our program. I have some prior experience with C++, so the Arduino portion of the code was not too difficult for me, however I am relatively new to MATLAB. I learned a lot about Arduino to MATLAB communication and some more niche skills about MATLAB Ui figures and pixelating an image.

These skills can help me in the future as I will have to work with a team again and go through the design process, most likely in even more detail. I can also use the programming skills in the future as I will need to use Arduino and MATLAB again.

18.4 REFLECTIONS ON WORKING IN A TEAM

This project improved my leaderships skills and overall team working skills. This was the first time I have worked with the same group on one project for a long period of time. Due to the nature of this project, I was able to improve my communication and leadership skills. Communicating our schedules with each other and what we each needed to get done was very important to the success of our project. I also learned how to effectively make decisions with a team and to be honest with each other about our ideas to create a better product.

Time management was difficult to learn since we all had different schedules. While we initially tried to all meet to complete every aspect of each milestone as a team, I slowly learned that balancing individual work with group work was important to complete tasks by the deadline. I personally also struggled with the workload and timeline of this project since we had a lot to accomplish by our deadline, but I learned to be more proactive with my work instead of leaving it for the last minute.

I would describe my leadership style as active and communicative. I am always ready to step and take charge, especially when necessary for my team's success. I enjoy sharing my ideas with my teammates and hearing theirs, however I struggle when I must always initiate communication and encourage others to share their ideas. I do not mind being the main leader, however when working in a team I prefer there to be an equal delegation of work since I do not want to overpower anyone's ideas. I also do not mind being on the receiving end of management, as long as I am not being told exactly what to do and how to do it and instead given some freedom.

I think my greatest asset to this team was my leadership skills. I often facilitated our meetings and delegated work when tasks had to be split up. I also stepped up and took some of the larger tasks upon myself such as the code of our exhibit when others did not seem as interested to do so. I think I helped keep our team on track as well by often reminding us of our deadlines and what we needed to complete for each milestone.

Our team handled adversity relatively well and we were able to adapt to work around issues that came up. When we had issues with our design or our code, we were able to come up with solutions that allowed us to work with what we had instead of scrapping it completely.

If I could do this project again, I would adjust our group's team contract and our expectations for each other. While we had talked about how we would handle issues, we were not very specific in our contract and did not have a structured way to approach these problems. I also would have worked harder at the beginning of our project to focus on the planning of our design process. I think I would have benefitted from outlining the project more and taking advantage of resources such as the Gantt chart to visualize our goals for the week and for the future.

If I had more time, I would have liked to add more to the MATLAB program or to the physical model to increase how intuitive the design was. I was proud of the exhibit we created, so it was disappointing that it did not make as much sense to our users. Adding further instructions on the MATLAB display or clearer indications on our model might have helped in doing so.

CARLY ROBINSON

19 DISCUSSION

After completing our design, we can conclude that our design was successful and met many of the requirements laid out in the problem statement. This can be concluded when compared to our problem statement and the evaluation planning chart that our team created to ensure our success. While some criteria were met short, our team was able to accomplish these goals through other aspects.

19.1 EASILY MEASURED GOALS AND REQUIREMENTS

Comparing the data from our design process, we can conclude that the exhibit fits the requirements of six out of the eight criteria from our evaluation planning chart.

In terms of the design being portable, our team determined that the design must fit within the size requirements and be able to be carried by one person. We used this as data to sufficiently say that the design is portable because it will exemplify the ease of transporting this design. With this data we were able to conclude that it is portable because we were able to carry it from our dorm to the expo multiple times.

Easy setup was another criterion that successfully met the requirements because we were able to spend less than three minutes setting up the project. As seen in our demo video, our setup and disassembly of the project took less than three minutes. This demonstrates that there is no difficulty or struggle when setting up the project.

The design also had certain size constraints. It had to measure 36’ x 28’ when set up, and after we measured the final design, it fit this criterion. We used a ruler to measure the size of the design.

Another criterion for the project was that the material for the entire museum must cost under $1000 per exhibit. In our design, specifically, it must cost under $100. Now, after completing the project, our total cost of the project was $84.65. This is under the constraints of $100 and the value ($285) of our design is under $1000.

19.2 HARDER TO MEASURE GOALS AND REQUIREMENTS

Of our list of criteria there are some requirements that are more difficult to discuss and analyze.

Educational is one of the first requirements and we were planning on collecting data by including a quiz at the end of the activity to ensure that the user understood the material. Even though we did not include a quiz at the end of the activity, we were able to include information aspects on our poster and within the instructions for the design when interacting with the design. I would constitute this criterion, however, as unsuccessful because of the lack of numerical data and input from the users regarding their educational experience with this design.

Safety was another criterion that was more difficult to analyze. Even though it is more difficult, we deemed this as a success. Of the users, none reported any injuries. In our team’s evaluation planning, we determined that zero injuries constitute a success since it means that some part of our design is not safe for the user. During the presentation of our design, no injuries occurred, which determines our project as a success.

A game-like design was another part of our requirements that is harder to discuss and analyze. Our plan was to collect data on how many times the users interacted with our design to demonstrate that it is eye-catching and promotes their knowledge regarding the James Webb Telescope. While we did not collect a numerical number of the exact number of times users interacted with our design, we observed many people interacting with the design. Sometimes, users would use the design multiple times, typically depending on if they shined the light long enough at the photocell. Despite these observations, I would deem this unsuccessful due to the lack of exact, numerical data.

Durability was our final criterion because we planned on collecting our data by measuring whether the design could withstand transportation, setup, and breakdown. If any object of our design is not broken, then we could deem this requirement as a success. We did this because any object that breaks from the design could be a hazard for the user. I would consider this requirement as a success because there were no elements of our design that were broken after the engineering expo and after being used by many users.

20 CONCLUSION

Our client requested our team to build an interactive space exploration museum exhibit that is portable so it can be a part of a traveling museum for middle school and high school students. This will allow the users to gain more knowledge on space exploration and encourage their interest in space.

With this request, our client has also given our team a few constraints to best fit their needs and the user's interaction with the exhibit. The design must sit in a 36" x 28" tabletop area and must be safe during all stages of the design's use. The design must also cost the museum less than $1000 per exhibit when it is finally produced in bulk. It must also fit within the given bag for easy transportation.

After much consideration with the engineering design process, our team decided to create a design based on the James Webb Telescope. We used both the lateral thinking and the vertical thinking methods to come up with a range of design ideas to best fit the client's needs and wants and the users' overall experience. From these methods we came up with a list of ideas and ended up deciding on our Model Telescope idea. We chose this idea using the Rank Order Chart and Kepner Tregoe Decision Analysis Method to place numerical values on the ideas to determine the best-fit design.

Overall, our developed solution met most of the requirements given by the user. From our team's Evaluation Planning Chart, we could collect data from aspects of our design to determine whether it was successful or not. Out of eight criteria, we can confidently say that six out of the eight were successfully met. These criteria had numerical data that supported the client's requests and benefited towards the user's experience with the design.

Even though we met most of the criteria, we did fall short on some. The educational and game-like design were the two criteria that we were not successful in meeting, which did not enhance the user's experience with the design. Overall, though, I would constitute our design as successful, but with a few shortcomings that can be improved with more time.

Our team had a successful design process for undertaking the problem, which led to the success of our final developed design. Through our background research, we gained more insight on space exploration and techniques that best support the user's learning on the topic. This also allowed us to come up with a Problem Statement. It took our team a bit to come up with a final, solid Problem Statement, but once we did, it was very clear and informative about the problem that our client needed to be solved. From there, we came up with an extensive list of ideas (around 10 designs in total) and we analyzed each design carefully and then used the Rank Order Chart and Kepner Tregoe Decision Analysis Method to determine our final design decision.

Implementation of this finalized design was successful. We first created a prototype out of cardboard, wooden dowels, and hot glue. This prototype allowed us to visualize what our final design would look like, and we could think more critically about which areas needed to be improved. For example, we noticed that attaching the secondary mirror to the primary mirror might be a more difficult process than we initially anticipated. We brainstormed ideas regarding materials and ways in which we would attach the two pieces together to be safe and durable in our final design. Thus, when we built our final design, we had a strong understanding on how we would build the design and ensure that it would be successful for our client.

Our design has a potential impact that must be analyzed for the benefit of all users and society. Our design can impact the education of the users on the James Webb Telescope and how the real-life telescope works in taking pictures and collecting data for NASA. The precision of the light from the flashlight ensures that the user understands how the telescope analyzes data in space and sends it back to Earth. One negative impact that the design may impact, is the misuse of the flashlight. With a younger audience of users, the design may pose some risks due to the ease of moving the flashlight at any angle and harming the user or people nearby.

21 RECOMMENDATIONS

21.1 EDUCATIONAL DATA COLLECTION

One area which our team fell short on was the collection of data to determine whether our design could be deemed educational for the users. With more time and resources, our team can dedicate more effort in building an aspect that would evaluate the user's comprehension of the material of the design. We could go back to our flowchart of the programming process and include a mini quiz.

This quiz could be evaluated at the end to collect data on how many questions the user got correct. To make this aspect simpler and easier, we could include two more buttons that would represent "Yes" or "No" and the user would respond to the given question with one of these answers.

By incorporating this into the design, our team could also collect data on how many times users interacted with our design. This would also contribute to verifying with numerical data if our design is game-like or not.

21.2 LIMIT FLASHLIGHT MOBILITY

Flashlight mobility is another aspect that could be improved with more time and resources. We want to minimize any potential hazard of our design, and misuse of the flashlight could injure people. One way in which this could be addressed is altering our AutoCAD designs to create a rotating box that supports the flashlight. The box would have limited rotation, so that the user can still successfully de-pixelate an image but limit any risk of injuries.

21.3 EXPANDING COMPUTER BOX DIMENSIONS

The box to cover the computer is another aspect that can be further improved. The aim of the computer was to make the design simpler for the user when interacting with the design. It also protects the user from the electronic components and any risk of damage to the computer. In the future, the width and weight dimensions of the box can be expanded to allow more room for all pieces to fit.

We ran into some slight issues with the size of the button. It did not fit entirely well over the computer, and more height from the box would have been beneficial. A larger width of the box would also allow the computer to be covered more and allow the electronic components to fit better and more safely away from the users.

This alteration to the design would allow the design to be safer for the user and allow the design to be more aesthetically pleasing.

22 LESSONS LEARNED

22.1 CONTRIBUTIONS

Over the course of milestone 5-7 I contributed towards mainly the building aspects of the design. I helped build the base and put the pieces together. I helped cut the boards with a handsaw, and once each piece was done, we glued each of the boards together. The boards were not all aligned so we decided to sand the sides down before painting. We did this to make the design more visually pleasing and make sure that none of the users could risk getting splinters and any other injuries from the design. See Appendix G, Figure 46 of the boards that were cut for the base before being attached and sanded.

I also built the laser cut aspects on AutoCAD. Not all the parts were aligned well after laser cutting, so I also sanded down some of the knobs so that the design fit well, and our team worked together to glue and attach each of the pieces together. I also helped glue and nail the computer box so that it would be secure and would not pose any hazard to the user when interacting with the design. See Figures 30, 31, 32, and 33 of the objects designed on AutoCAD.

Figure 31 AutoCAD drawing for computer cover sides

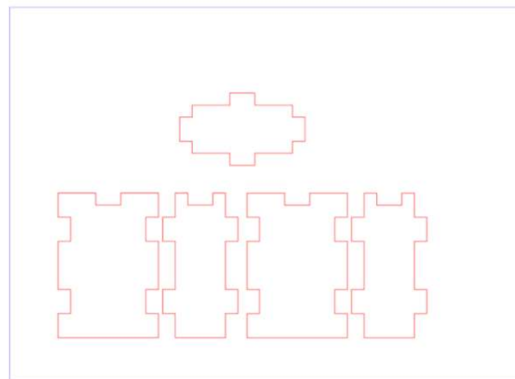

Figure 32 AutoCAD drawing for back of mirror

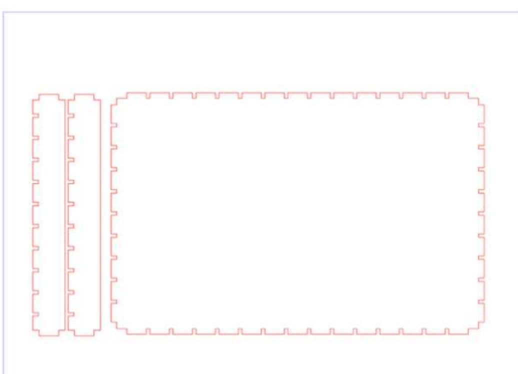

Figure 30 AutoCAD drawing for computer cover

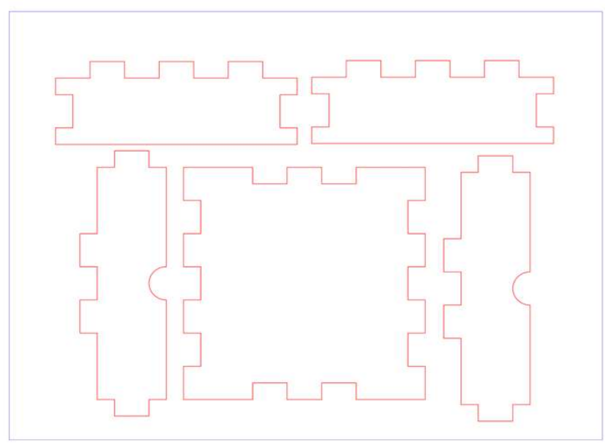

Figure 33 AutoCAD drawing for base of design

Once we had finished putting all the parts together for the design, I brought the design back to my dorm to paint it. This allowed the design to be more visually appealing to people walking past our design and encouraged them to interact with our design. See Appendix C, Figure 53.

22.2 RESOURCES

Our group met the requirements of the budget and spent a total of $84.65. Of this amount, I spent $24.09 on mainly materials from Blick to make our design look more visually appealing to users. This amount went towards purchasing wood for laser cutting. For the prototype, I also collected various pieces of cardboard for the project. As a group, we also acquired multiple items from FYELIC such as hot glue guns and sticks, screws, and wooden dowels.

In total, from milestone 1 to 6, I spent a total of 38.5 hours devoted to our project.

My experience from this project has positively impacted my understanding of resource management. Going forward, I have a better understanding of the benefits of being proactive in attaining materials. This prevents any last-minute rush for materials. It also prevents unnecessary spending of materials because there is more time to purchase or acquire the needed materials. I can take this understanding and apply it to future projects.

22.3 REFLECTIONS ON LEARNING

From this project I gained valuable lessons regarding the engineering design process. One of the most valuable lessons is time management. I learned how to designate time towards the project and communicate my availability when our team needed to meet during the week. I also learned more on how to use various applications such as AutoCAD and creating wire diagrams. I spent valuable time thinking about the best ways to set up our design on these applications to best fit our design and the client's needs. On AutoCAD, I also learned how to laser cut objects so that each piece fits well with one another.

Laser cutting objects was a new experience for me. Also spending more time critically thinking about how our design would best support our client's needs was new and taught me how to analyze each aspect to see its purpose with the rest of the design.

Throughout this project, I taught myself how to laser cut pieces on AutoCAD. I am proud that I have a better understanding of how this application works. This was a trial-and-error process, as I was not always successful in getting all of the pieces to fit. However, I now know ways in which I can approach this issue in the future, and I know what approach I should not take when laser cutting.

In terms of my future career, I now have a more in-depth knowledge of AutoCAD and creating wire diagrams. AutoCAD is helpful because I can create pieces to be laser cut so each aspect of the design can fit better and look more visually appealing. The wire diagram also is helpful because it allows us to visualize how the circuit will be set up, so we have an easier time setting the design up. I also can apply my knowledge of time management for my future career because I have a better understanding of how I can designate time during the day to focus on my project. Overall, I learned more about patience during the engineering design process. This is a lengthy and time-consuming process; however, each part is crucial in designing a successful design for the client. This also gave me more time to think more critically about my work and how each aspect of the design plays a part in the overall impact.

22.4 REFLECTIONS ON WORKING WITH A TEAM

Our team focused more on our time management and communicating times in which we would all designate time to work together on the project. Compared to our last project, we did not have to put in as much time compared to this project, so finding a time for us all to meet was a change in our team's working skills. The spread of work was also another skill that we had to change a little due to the large amount of time that we all had to spend in designing the project. Personally, I think that we still need to improve in these areas, but I feel that we have made good improvements since the previous project.

I would describe my leadership style as democratic. I would say this because I think that I shared leadership with other members of my team. We all discussed our ideas and analyzed them together to determine each of the pros and cons. I found this helpful and beneficial for our team because it allowed us to be on the same page. This also allowed us to be more engaged with the project and assess each of the components of our project and their benefit to the design. I think my ability to be managed was positive because I was open to criticism and ideas from my other team members.

I would say my biggest asset to the team was attending as many meetings as possible to allow myself and the rest of our team to have a collective understanding of our goals. I would also say that another asset of mine would be helping to organize our ideas and planning ahead for our future meetings, such as getting materials or appointments. I enjoy planning ahead and being timely on work and meetings, so this was something that I played a part in incorporating into our team dynamic.

Going back, I would reassess our group's scheduling method. We made a table in our design notebook, and we would try to update it each week. However, I think after a bit we did not rely on this resource as much and I think scheduling and blocking out time, as a group, for the project became a little more difficult. I think if we stuck to this method or tried a different way to schedule meetings, scheduling and overall project management could have been easier.

If we had had more time for the project, I think it would be nice to make the design more aesthetically pleasing. We painted it a little bit, but I think we could have added more designs and paint to make our final design look more similar to the real James Webb Telescope. I would also incorporate a small quiz at the end of the user interaction with the design to ensure its educational aspect.

PIPER SCHMIDT

23 DISCUSSION

I believe our product was successful in fulfilling the constraints and requirements provided by the client as well as the goals we hoped our design would reach. We kept the constraints, requirements, and goals outlined in our problem statement in mind throughout the design process to ensure our final product met them.

23.1 EASY TO MEASURE GOALS AND REQUIREMENTS

The constraints which were easiest to measure are the size and price requirements set by the client. You can review our bill of materials to see that our final product came in under the $100 price limit at $66.08. The value of our design also came in under budget at $261.54. Our final design fits within the travel configuration size and was able to be set up at the expo on our 28” x 36” table area. The design is also successful in portability as it was light enough to easily be carried to the expo by one person and was quickly set up in under two minutes. While this would depend on who is setting it up, I would assume it would still be under five minutes even if you were not familiar with how to set it up. To create a successful exhibit we decided, based on our research, that the activity needed to be game-like. Since we introduced the timing aspect and created a clear way to win or lose the activity it is game-like. Our problem statement outlined our desire for the exhibit to be colorful and eye-catching. While this is more subjective than the previous constraints, our poster clearly displays colorful images and text. The model itself is also quite eye-catching since it is a more unique topic. The cost, size, and portability can be easily quantified as successful. The game-like aspect and eye-catching effect of our exhibit are a bit harder to judge but are clearly successful as well.

23.2 HARDER TO MEASURE GOALS AND REQUIREMENTS

It is harder to measure if the exhibit was fun, educational, durable, safe, and if the user was satisfied since these are qualitative. I feel confident saying that the exhibit was fun based on feedback from our peers and observing users interact with our activity. When we asked our peers if they would play our game again and recommend it to a friend 100 percent said “yes”. When observing users interact with our activity they were smiling and eager to try it out. These are strong indicators that our exhibit was fun and engaging. While it is easy to see that our poster contains educational content it is much harder to judge whether or not that content was read and or retained by the user. This is an area I feel was unsuccessful, since while watching users interact with our exhibit they seem very engaged with the game, but many seemed to ignore a lot of the content on the poster. If we had incorporated more educational information into the game this area may have been more successful. I also believe our project was not as durable as it should have been. While this did not appear to be a problem, we had a few more fragile pieces, like the wooden dowel which attached the secondary mirror to the primary. If we had replaced these with metal our model would have been more durable. We appeared to be successful in creating a safe product since no user was injured or negatively impacted after interacting with our exhibit. However, I would like to observe more users interacting with our exhibit to feel confident in saying this aspect was successful. User satisfaction is also critical to the success of our exhibit. After watching many users interact with our exhibit they seemed to be engaged by our game and model commenting positively on both. Our peers' feedback also indicated that the exhibit was successful since they all said they would play again and recommend it to a friend. Overall, I am confident in saying that our exhibit was successful in user satisfaction.

24 CONCLUSION

24.1 THE PROBLEM

Our final solution addresses the client's need for an interactive and portable museum exhibit to aid in educating students in rural and underprivileged communities who don't have access to museums or other hands-on learning tools. The client requested the exhibit to be themed around space exploration and geared towards students from middle to high school. The solution should be educational and interactive. It must be portable in a large tote bag, set up within a 28" x 26" table, valued at under $1000, and the prototype we develop must cost under $100. Our research indicated the best way to engage children was with a game-like activity and eye catching features to display information. Given the target audience it is also important for the exhibit to be durable and safe to all users and facilitators. The main stakeholders we have considered are the students using our exhibit and the educators who will be setting up and facilitating its use.

24.2 OUR SOLUTION

Our solution is a model of the James Webb Space Telescope, to teach students how it is aiding in space exploration. The exhibit consists of educational content conveyed through a poster board to teach users about the telescope and how it works. To reinforce this information we created a game where users will walk through the image capturing process on our model telescope to "produce" an image that the real telescope took. Users will shine a flashlight at the primary mirror which will then be channeled and reflected off the secondary mirror and onto the photocell. A photo from the telescope will then come up and begin pixelating, as the light continues to hit the photocell, until the image is clear. If the user is able to complete the image before time is up they win. We focused on creating a product that would be durable, safe, educational, interactive, fun, and portable.

24.3 MEASURING OUR SUCCESS

At the preliminary in class showcase and final showcase we were able to collect some data to gauge if our product was successful based on our own goals and the client's requirements. Through a peer feedback survey we gathered that 100% of users would play our game again and 80% found it educational. We feel that the first metric indicates our exhibit is fun for users. However, the second metric indicated we could improve on the educational value of our design. We added the poster to our final exhibit, however, we still observed many users skipping over this content and just playing the game. Feedback we received from users at the showcase indicated our game is fun. Many users played more than once and commented positively on the experience. We concluded our design was successful in safety and durability since it was not damaged and no user was injured. More data could be taken here since the exposition was only an hour and thirty minutes. Finally, our exhibit is portable, we were able to bring it to the location with ease and set up in under three minutes. For more specific data on our results please refer to the results section of this report.

25 RECOMMENDATIONS

25.1 STRUCTURAL IMPROVEMENTS

The structure of the final model can be improved upon from our prototype in a few ways. The boxes that house the electronics, hide the computer, and create a stand for the model should be streamlined with more accurate dimensions. The boxes do not fit together as well as they could, so resizing the dimensions of the cutout pattern to properly fit together would make the build process easier and improve the aesthetics of the boxes. While this is not a big deal since the boxes still function as they should, it is an easy area to improve.

25.2 PHOTOCELL RANGE

While we found a few ways to make our game harder for the user throughout the design process, I feel we could have made the model a bit more accurate and the game harder for the user. I suggest the model be improved by adding a small cover around the photocell to block it from picking up light that comes in from the sides. While we were able to calibrate the photocell to neglect the light in the room, it is clear from our own testing and watching users interact with the device that it still picks up a great amount of light from the side. If a small tube shaped cover, which could easily be 3D printed, was added around the photocell the game would be harder for the user and a more accurate representation of how the real telescope works.

25.3 DATA COLLECTION

Another area our team could improve upon is collecting user data. While we were good about observing users at the expo it would be much more efficient if the code collected user data for us. I specifically would suggest that the code tracks the number of users, how many users are successful, and how many users press play again. Tracking the number of users would be helpful to see how attractive our project is, especially when we cannot be there to monitor it. Tracking how many users are successful would be helpful in gauging the difficulty of our game and if it needs to be made more challenging or not. Finally, tracking how many users press play again would be a good indicator of how fun our game is. Adding some data collection features into the code would allow informed improvements to be made later on.

25.4 EDUCATIONAL CONTENT

I believe our trifold was educational and engaging since we received positive feedback from those who interacted with it. However, I believe many users neglected the information and opted to just play the game instead. The overall success of the exhibit could be improved by integrating some of the educational content into the game to ensure users receive the educational benefits of our exhibit because that was the main requirement of the client. To do this, I would recommend requiring users to answer a question about the telescope to be able to try the game. The answers to the questions should come right from the information provided on the display to make it easy enough to find the answer and keep students engaged. If the answer is too hard to find I think many users would give up on trying and game altogether.

26 LESSONS LEARNED

26.1 CONTRIBUTIONS

For the construction of our final model I worked mostly on the primary and the assembly of the model. For the primary mirror, I attached the mirrored tiles to the plastic backing and created the cone shape of the mirror assembly. I glued together the box to stand the base on and the box to house the electronics behind the primary mirror. I then nailed the base onto its stand to secure them together. I worked on attaching the primary mirror to the secondary mirror, using the wooden dowels to attach them. I also secured the electronics box onto the primary mirror and the primary mirror to the base.

I worked on the wiring for all of the electronics. I helped set up the two circuits and thread all the wires through our model to the RedBoard. I worked on the code, helping to start off the process and outlining what we wanted the end result to look like.

For our exhibit, showcased at the end of milestore 6, I created the poster with the educational content. I gathered and condenced the information to be presented and created a few graphics to display the information on the poster. I printed out picture the telescope took to draw more attention to the information and put it all together. See figures 34, 35, and 36.

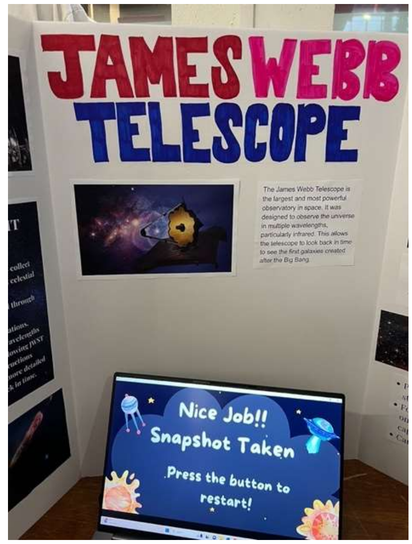

Figure 34 Center Poster

Figure 35 Left Poster

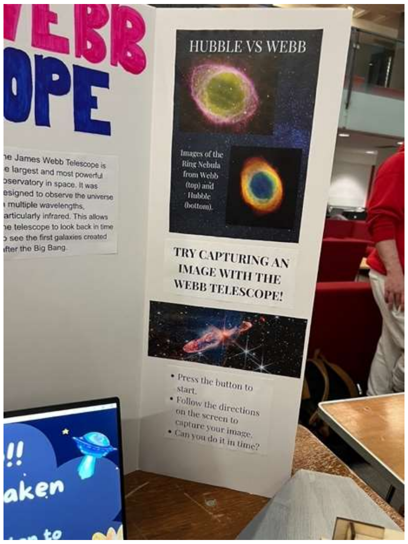

Figure 36 Right Poster

26.2 RESOURCES

Our team stayed under the $100 budget, spending only $84.65 on materials for our prototype and exhibit. Our value was also under the $1000 limit, at $285. I personally spent $34.58, purchasing the flashlight, poster, markers, printing paper, and wood from the bookstore. We were able to aquire most of our resources from FYELIC and our SparkFun kits. I was able to aquire these resources from Amazon and CVS.

From Milestone one through six I spent 37.5 hours working on our project. My lowest number of hours was 2.5 on milestone 1 and my highest was 8.5 during milestone 3 when I was project manager.

Throughout this project we closely tracked our resources, materials, expenses, and hours, this has made me appreciate the benefits of resource tracking. Tracking resources showed me how much we were saving by finding and reusing material, which will be important to keep in mind on future projects. Tracking expenses showed me how quickly they can add up, while $80 may not seem like a lot, throughout the project I felt like we were barely spending any money. Tracking hours helped me hold myself accountable. Being able to see how many hours I spent on our project compared to my team members helped me to gauge when I needed to contribute more.

26.3 REFLECTIONS ON LEARNING

Fully working through the engineering design process is new to me. I learned how important the initial research is and how it can carry you through the rest of the process. I was surprised by how much preparation we did before we started building our model. Previously, I would have thought to start by building the model, but that was one of the last things we did. The most important lesson I learned was to stay realistic and start with basic function, like our proof of concept, and then expand the function to make it more interesting. We prioritized function and were still able to make aesthetics motifications that greatly improved the quality of our game, however, if we started with this more complex version we likely would have been discouraged.

From this project I learned some new AutoCAD skills, how to create wire digrams, and new code commands. Our game required some MATLAB commands I had never used before, figuring out how to pixelate an image. I also learned some skills from the physical build process. I have never had to build a prototype before so the physical build was challenging for me, but I am proud of the skills I have developed from it.

In the future, I will use the skills I learned working on this project to feel confident building future prototypes and working in a team. I will genuinely invest in my future design processes since although it is tedious it was a very rewarding step in creating a solution.

26.4 REFLECTIONS ON WORKING IN A TEAM

This project greatly improved my team work skills. I have never worked on a team project with this many segments or this long of a duration. Because of this, my communication and time management greatly improved. It was a challenge to coordinate schedules and delegate tasks to be done individually. At the beginning, we were trying to find time to meet and accomplish most tasks as a group. However, we soon realized this was unrealistic and started to delegate tasks, complete them individually, and then go over them as a team. This made us much more affective as a team. However, we could have done a better job of volunteering for tasks to equally divide up the work. I could have done a better job, as project manager and after, of holding my teammates accountable to this.

My leadership style is passive. I enjoy being in charge and outlining the work that needs to be done, but I have a harder time specifically assigning tasks. I prefer to outline what needs to get done and encourage people to take tasks that fit their strengths. I need to work more on being assertive as a leader. In term of being led, I love to collaborate and am happy to take instructions from team member. However, I don't like to be told specifically how to do something. I believe my biggest asset to our team was my leadership and organization. I was frequently breaking down the tasks that needed to be accomplished each milestone and making plans to meet and accomplish them.

If I had to start this semester over, I would have encouraged my team to be more specific in our team contract. It was naïve to think we wouldn't run into issues and we did not have adequate plans in place to address them. I also would have encouraged us to set up meeting times for the week sooner. We planned on doing this, however, it often didn't get done as soon as it should have which led to last minute cancelations and no-shows. I also would have encouraged us to start using the design notebook sooner. We became much better at documenting our progress in it. However, at the beginning we missed details of our process.

RAIN GATRELL

27 DISCUSSION

Upon completion of our design, we can confidently assert that our project has been successful in meeting the requirements outlined in the problem statement. This conclusion is drawn after a thorough comparison between our design outcomes and the criteria established in our evaluation planning chart, which served as a roadmap to ensure our project's success. While some aspects may have initially fallen short of the criteria, our team successfully addressed these deficiencies through additional efforts and innovative approaches.

27.1 EASILY MEASURED GOALS AND REQUIREMENTS

Upon completion of our design, we can confidently assert that our project has been successful in meeting the requirements outlined in the problem statement. This conclusion is drawn after a thorough comparison between our design outcomes and the criteria established in our evaluation planning chart, which served as a roadmap to ensure our project's success. While some aspects may have initially fallen short of the criteria, our team successfully addressed these deficiencies through additional efforts and innovative approaches.

27.2 HARDER TO MEASURE GOALS AND REQUIREMENTS

Certain requirements, such as educational value and game-like engagement present challenges in estimating their success. While we initially aimed to incorporate a quiz component to evaluate user comprehension, this aspect was not realized within the project timeline. However, informative content displayed on our poster and within the exhibit's instructions aimed to compensate for this shortfall.

Safety, a paramount concern, was rigorously addressed, with zero reported incidents during the exhibit's presentation. This positive outcome validates the safety measures implemented and ensures user well-being.

Although we observed high user engagement with our exhibit, precise numerical data on user interactions was not collected. While anecdotal evidence suggests significant user interest and interaction, the lack of quantifiable data prevents a conclusive assessment of the exhibit's game-like qualities.

Regarding durability, our exhibit withstood rigorous testing without any components malfunctioning or breaking, affirming its robustness and safety for user interaction.

28 CONCLUSION

In addressing the problem statement presented by our client, we embarked on a journey to create a portable, interactive learning experience centered around space exploration for middle and high school students in rural areas with limited access to STEM-related content. Our goal was to provide an engaging platform that fosters curiosity and learning outside traditional classroom settings.

Through meticulous research and iterative design processes, we developed a solution that meets the diverse needs of our stakeholders. Drawing inspiration from successful museum exhibits and educational practices, we crafted an exhibit that combines informative content with interactive elements to create an immersive learning experience.

Our solution successfully addresses the given problem by offering a portable exhibit that encapsulates key concepts of space exploration while promoting user engagement and interaction. By incorporating game-like activities and educational content, we aim to spark curiosity and facilitate learning in young minds.

In assessing the effectiveness of our design process, we identified areas of success and areas for improvement. While we excelled in meeting easily measurable goals such as safety and durability, we recognize the need for more robust data collection methods to evaluate educational impact and user engagement accurately.

The potential impact of our design extends beyond mere educational value. By offering an accessible and engaging learning experience, we aspire to inspire the next generation of scientists, engineers, and space enthusiasts. Moreover, our exhibit holds promise for future iterations, with opportunities for expansion and refinement based on user feedback and technological advancements.

Moving forward, we recommend further expansion of data collection methods to better assess educational outcomes and user engagement. Additionally, enhancements to design accuracy and user experience, such as clearer instructions and streamlined presentation, can elevate the exhibit's effectiveness.

Our journey in creating this exhibit has been marked by invaluable lessons in teamwork, problem-solving, and resource management. As we reflect on our experiences, we recognize the importance of effective communication, adaptability, and collaboration in achieving shared goals. These lessons will guide us in future endeavors, ensuring continued growth and success in engineering challenges.

In conclusion, our project represents a commendable achievement in interactive exhibit design, offering a glimpse into the vast wonders of space exploration while empowering young minds to explore, learn, and innovate.

29 RECOMENDATIONS

29.1 EXPANSION OF DATA COLLECTION

To enhance the educational value of our exhibit, it is recommended to implement more robust data collection methods. This could involve incorporating interactive quizzes or assessments at the end of the exhibit experience to gauge user comprehension effectively. By integrating educational elements seamlessly into the exhibit, we can better evaluate its impact on knowledge retention and learning outcomes.

29.2 MORE ACCURATE DESIGN

Though our design was fairly accurate in comparison to the actual Webb Telescope in design, functionality, and general scale, we could have always done better to make it more accurate, Such as making the base of a thinner material that bent more, much like the actual telescope. Also, there was some questioning of whether or not the photocell actually got the reflected light, so we could have better ensured that it only got the reflected light instead of direct light.

29.3 AFTER EXHIBIT SUGGESTIONS

After our exhibit debut, we noticed many people asking for directions directly, instead of reading the steps provided. However, we believe that this is due to the ease of being led through steps, instead of the possibility of misunderstanding the written steps. This issue could be improved with larger words and pictures depicting steps. We also got the suggestion of using a monitor instead of a laptop. This is so the entire setup looks much cleaner and there is no visible keyboard.

30 LESSONS LEARNED

30.1 CONTRIBUTIONS

Throughout each of the milestones, I frequently put in my individual ideas and suggestions. I frequently made runs to Home Depot to collect any necessary materials that we could not get on campus. I frequently helped with the build of the project, most notably the base construction.

30.2 RESOURCES

Our team effectively managed resources within the allocated budget, with meticulous attention to detail in acquiring materials from various sources. My personal contribution included sourcing materials from Home Depot, where I obtained wood for building our base and other support wires. By leveraging a diverse range of resources, we maximized cost efficiency and project viability while maintaining high standards of quality and craftsmanship.

30.3 REFLECTIONS ON LEARNING

This project offered valuable insights into the intricacies of the engineering design process, highlighting the significance of effective time management, technical proficiency, and collaborative teamwork. The experience underscored the importance of strategic resource allocation and proactive planning in ensuring project success. Moreover, navigating challenges and adapting to unforeseen obstacles provided valuable lessons in resilience and adaptability, essential qualities for success in engineering endeavors. The opportunity to engage in critical thinking and problem-solving, particularly in material selection and construction techniques, further enhanced our understanding of the design process. Additionally, working within a team environment fostered personal growth and development, emphasizing the importance of effective communication, leadership, and mutual support in achieving shared goals. Looking ahead, the lessons learned from this experience will serve as a solid foundation for addressing future engineering challenges with confidence and competence.

30.4 REFLECTIONS ON WORKING IN A TEAM

Working within a team setting has been an enlightening experience, teaching me valuable lessons in teamwork and time management. Balancing responsibilities and deadlines proved challenging at times, requiring careful organization and prioritization of tasks. However, I found immense support from my team members, who held me accountable and provided invaluable guidance throughout the project. Their collaborative spirit fostered a sense of responsibility and commitment, pushing me to strive for excellence in my contributions. Through this process, I gained insights into effective communication, collaboration, and problem-solving within a team environment. While I am proud of our collective achievements, reflecting on the experience, I recognize areas where I could have contributed more effectively. Moving forward, I aim to apply these lessons learned to future endeavors, ensuring greater efficiency and productivity in my contributions to team projects.

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AUTHOR BIOGRAPHIES

Aashna D. Sahani is a current first-year student at Northeastern University Boston, Massachusetts, and is a candidate for a Bachelor of Science in Mechanical Engineering. She was born and raised in Lexington, Massachusetts and graduated from Lexington High School in the spring of 2023. She is expected to graduate from Northeastern University in 2027.

From 2020 to 2024, she was an active member of the elementary school STEM club and would educate and engage with younger students on a variety of science topics. She also worked as a sales associate at her local bakery, the Royal Pastry Shop, from 2021 to 2024, and as a camp counselor at the Hammel Tennis Camp from 2020 to 2024. She was a member of the Varsity Volleyball and Varsity Tennis team at Lexington High School.

Ms. Sahani is currently a member of the NU Robotics Club, the American Society of Mechanical Engineers, and the Indian Cultural Association.

Carly N. Robinson is a current first year, who is a candidate for a Bachelor of Science in Chemical Engineering and Bioengineering at Northeastern University, Boston, Massachusetts. She is expected to graduate in 2027. She was born and raised in Sudbury, Massachusetts and graduated from Lincoln-Sudbury Regional High School in Sudbury, Massachuset.

During her time in high school, she was actively involved with many clubs and athletics. She was a News Editor for two years in her school's newspaper and mainly wrote articles pertaining to her town's current news. She was also a part of the review team for her school's literary magazine. In addition, she also was involved with Model UN and two community service clubs at her high school. She was a varsity athlete on her school's Women's Rugby team and Swim and Dive team, as well.

At Northeastern University Ms. Robinson is currently involved in the Northeastern University AIChe Club, Northeastern University Catholic Center, and the Northeastern Women's Run Club.

Rain K. Gatrell was born in Charlotte, North Carolina, in 2005. He received his High School diploma from The Gow School in South Wales, New York, in 2023. He is currently pursuing his undergraduate degree in mechanical engineering from Northeastern University in Boston, Massachusetts.

From 2021 to 2023 he worked as an RA at The Gow School. He was appointed as student body vice president from 2022 to 2023. At The Gow School, he worked as head of electrical in the robotics program. He was a member of Varsity Soccer, Varsity Wrestling, and Varsity Track and Field. He was team captain for both Varsity Soccer and Varsity Wrestling. He competed at the New York State wrestling tournament in 2022. From 2023 to the present he worked as a Raft Guide at the U.S. National Whitewater Center in Charlotte, North Carolina. His research interests include prosthetic limbs, artificial biological designs, and cosmological analysis.

Mr. Gatrell is a member of the American Society of Mechanical Engineers, the National Mah Jongg League, Aerospace NU and Northeastern Wrestling.

Kate P. Schmidt is a candidate for a bachelor of science in mechanical engineering at Northeastern University, in Boston, Massachussets. She was born in Wilmington, Delaware in September of 2004. She graduated from The Hill School, in Pottstown, Pennsylvania in May of 2023.

In 2022 and 2023 she worked as a tutor and mentor to students at Servium Academy. She served as a Prefect at The Hill School from 2021 to 2023. She worked on the Student Life Association for all four years, as well. She was a member of the Varsity Field Hockey, Varsity Women's Ice Hockey, and Varsity Women's Lacrosse teams at The Hill School.

Ms. Schmidt is currently a member of the NU American Red Cross Club and the Northeastern Women's Club Ice Hockey team.

APPENDICES

APPENDIX A - TEAM CONTRACT

This memo serves as the team contract for Gnomes. 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

To respect our deadlines, we are going to meet 2 days prior to the submission deadline to confirm our work with the group. This is to make sure everyone has finished their assigned work and that we all agree with what is going to be submitted. We are also going to assign one person in advance to submit each assignment to ensure organized submission. We will set meeting times in advance (at least 2 days in advance) and let others know ASAP if one of us is unavailable. We will also make sure to update our calendars weekly. We will come prepared to each meeting with a few questions or ideas for the group to keep the meeting moving. We will hold each other accountable if someone violates these expectations, but by being prepared prior to deadlines, we are able to handle changes.

Commitment

To show our commitment to our team at the beginning of each week we will all update our availability on our calendar chart to ensure we can find accurate times to meet each week. We will communicate our conflicts in advance this way and expect each other to be accommodating and willing to meet when all members are available, even if it is not convenient for you. We will set meetings for the week on Sunday nights. We are all committed to submitting high-quality work and will put in the necessary amount of time as a group and individually. If we feel an assignment took us longer than usual or expected, we will complete it or reach out for help and reassess how we divide work in the following meeting. We will measure the quality of our work by having at least two members look at all minor assignments and everyone look at all major assignments. We will upload all work to the design notebook and feel comfortable making and checking for comments. If someone violates these policies, we will communicate from a place of empathy while holding each other accountable. Any violations may be brought up in team meetings to ensure we stay on track. If someone violates our agreement, they will be responsible for leading the next meeting to show their commitment.

Transparency

We will talk about any decisions and ideas throughout the project. If needed, we will also hold a vote (3 out of 4) regarding unresolvable disagreements for project decisions. We will record all information in the notebook so that all members of our group can be aware of the project decisions. If we run into a situation where someone misses a meeting, we plan to type up a summary to make sure that they can be aware of what decisions were made and they can also look in the notebook. If a member of the group feels excluded, we will make sure to check the notebook and keep it better updated.

Communication

To ensure we are communicating with one another in a timely manner, we will mainly communicate via text when apart. While physically together, it is important to ensure that everyone's opinions and ideas are heard. We will all be sure to say something during each meeting. If someone has not been sharing as much, we will allow them a space to comfortably share their ideas or opinions. If there happens to be a disagreement within the group, we will take a consensus vote to decide. If there is a greater disagreement that we do not believe can be fairly solved by a vote, we will get outside opinions from other peers or mentors. At the end of every meeting, we plan to reflect on our strengths and issues within our group. If there seems to be an issue that we need to improve on, we can work to implement our improvements before the next meeting.

Justice

We will assign different tasks to each person that are as equal as possible. We will speak up and reflect on the amount of work we put in the week before to adjust our tasks for the coming week. To prevent conflict, we will make sure everyone is on the same page about decisions before acting on them. We will also make sure everyone is able to share their ideas and that their ideas are heard by the rest of the group. If we notice someone is contributing less, we will talk about it at our next meeting and ask that person to share their ideas and opinions on the project.

Summary

This memo serves as the team contract for Gnomes 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 the team. Contact information available in Attachment 1.

Signed,

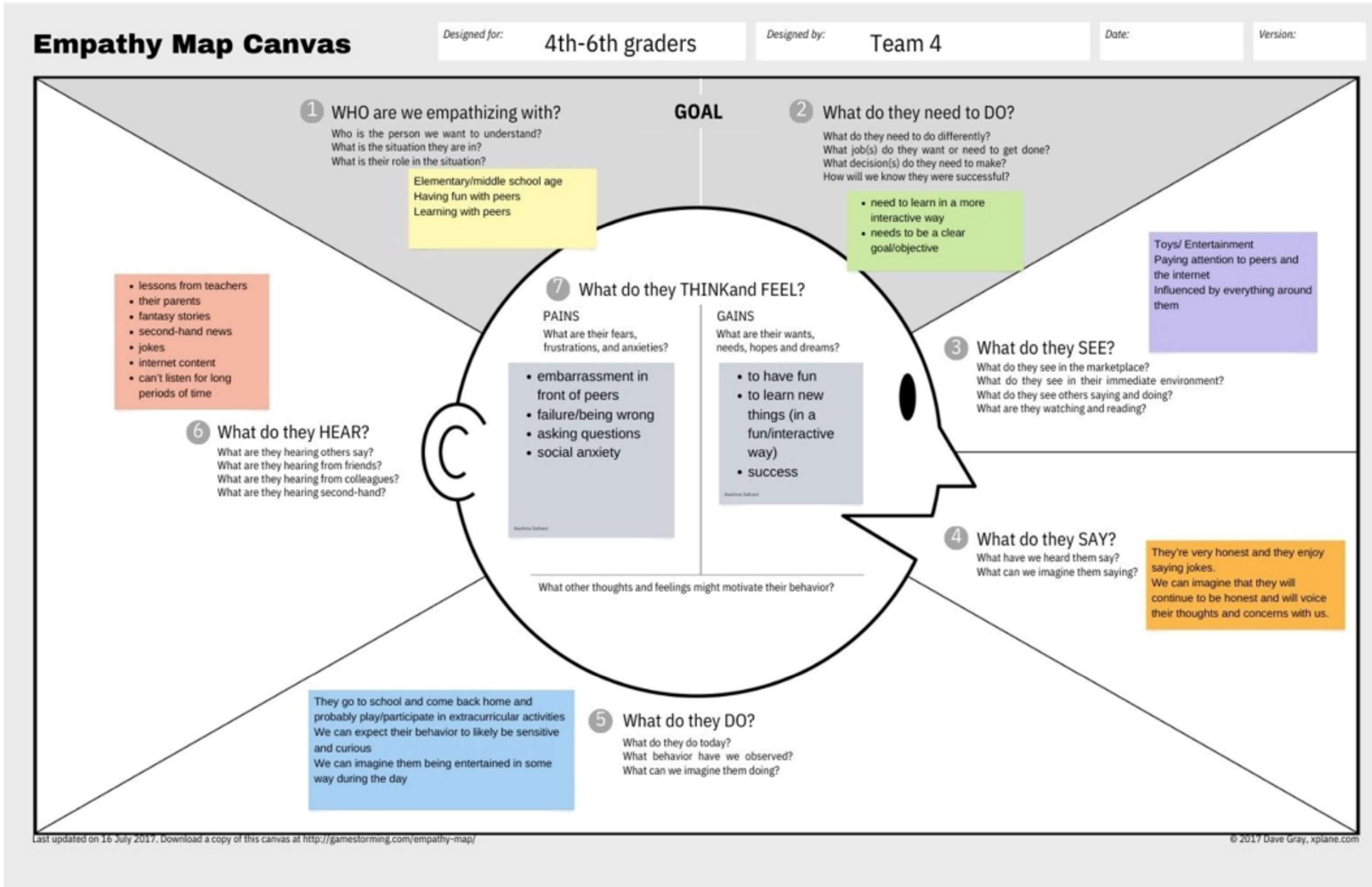
Aashna Sahani

Piper Schmidt

Carly Robinson

Rain Gatrell

APPENDIX B - EMPATHY MAP



APPENDIX C - AUTOCAD/SOLIDWORKS DRAWINGS

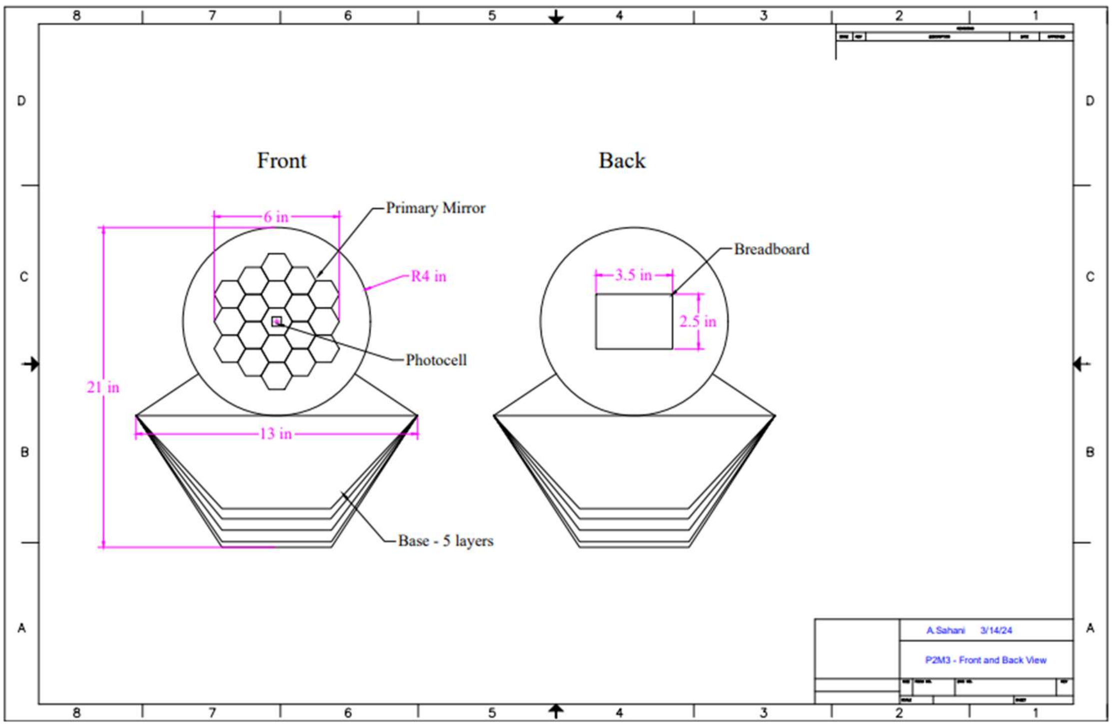


Figure 37. AutoCAD of Front and Back View of Model Telescope

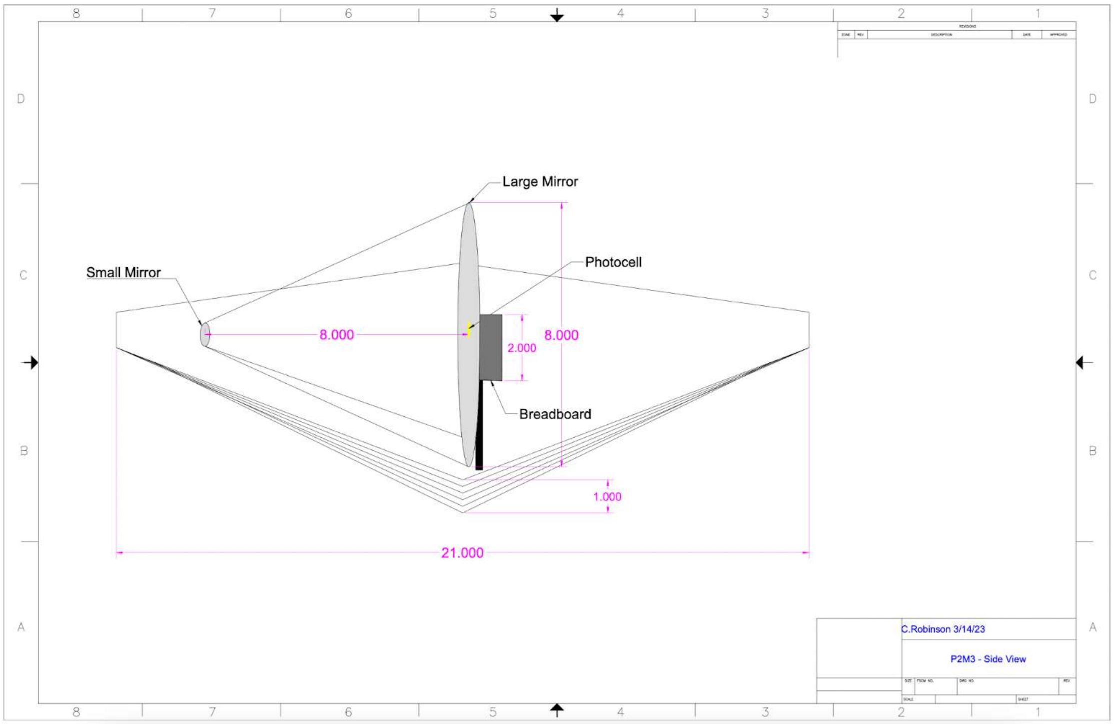


Figure 38. AutoCAD side view of model telescope

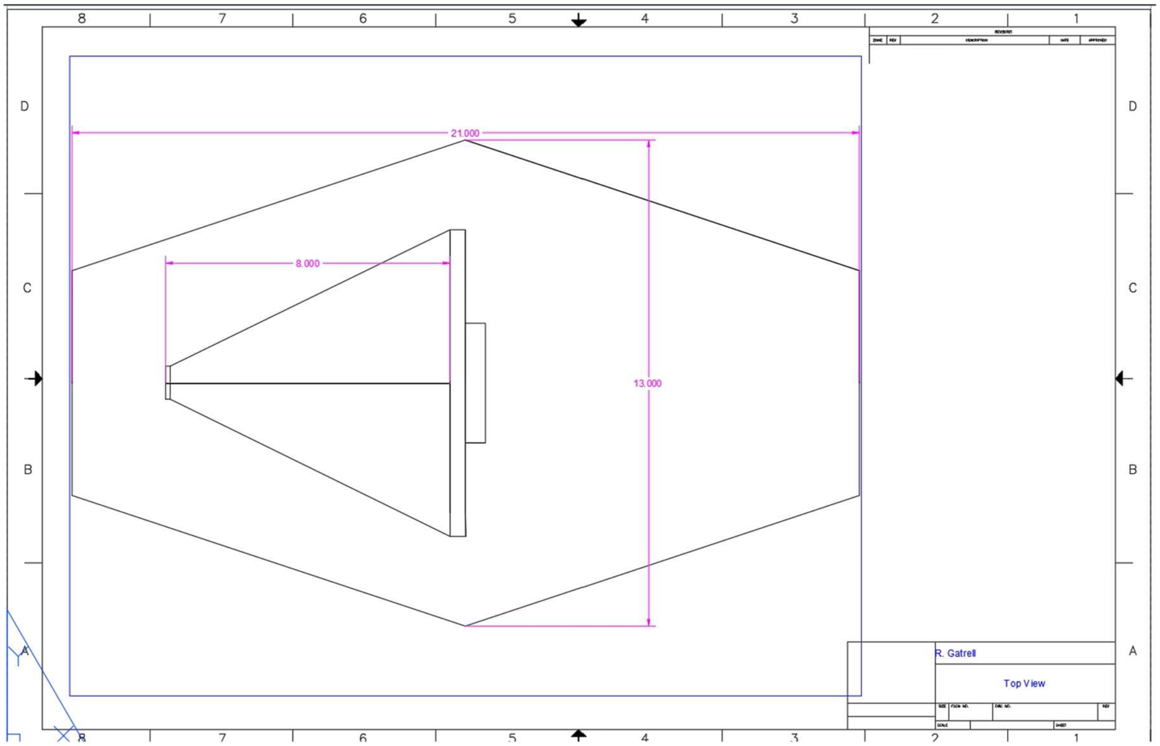


Figure 39. AutoCAD top view of model telescope

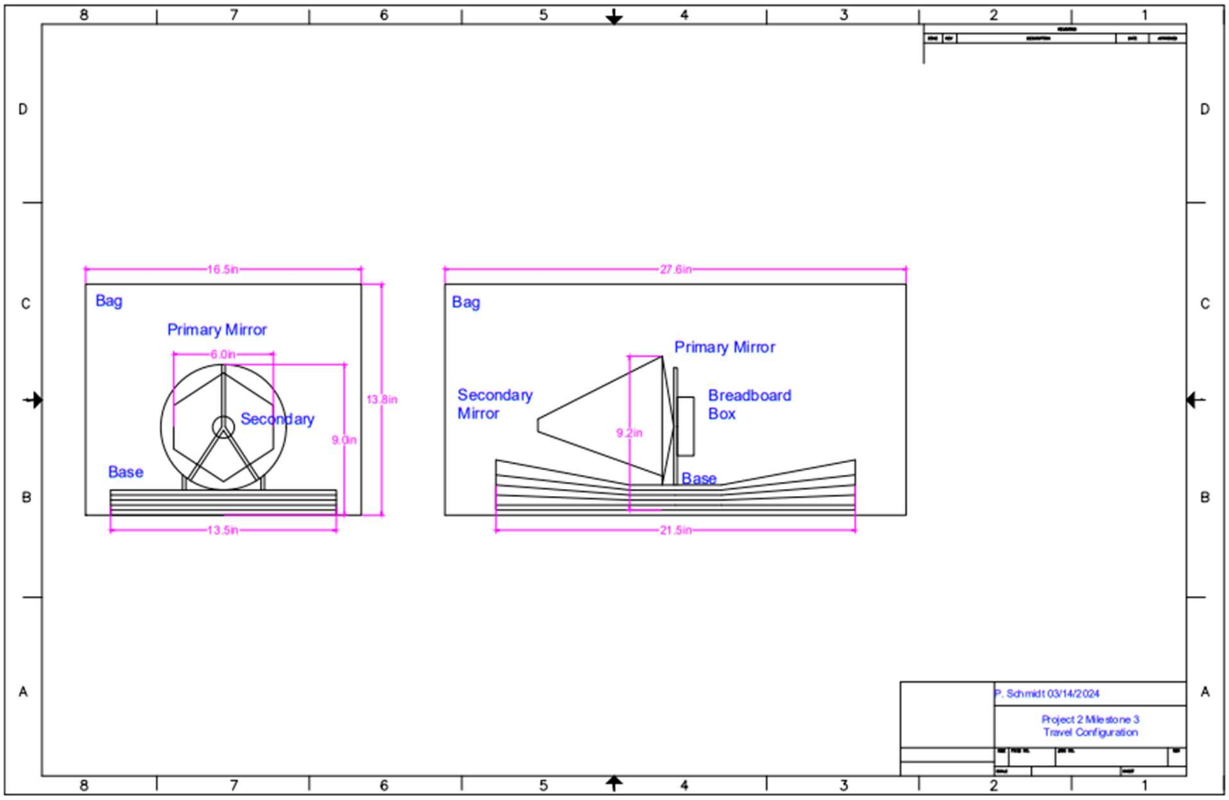


Figure 40. AutoCAD of configuration of model telescope in bag

APPENDIX D - PRODUCT TESTING RESULTS

Evaluation Plan:

Criteria What project criteria will this assess?	**Data** Data that would speak to the success or failure of criteria?	**Reasoning** Why do you believe that data will best speak to the criteria?	**Method** How will you collect the data?	**Analysis** How will you analyze that data to determine success or failure?
Portable science museum exhibit	Fits within requirements and can be carried by one person	This will show that it can be easily portable	During setup of the design	If it is able to get to the exhibit space
Educational	The quiz at the end of the activity will evaluate the user's understanding of the material	This will exemplify that the user was able to retain the information presented during the activity	We will have an online quiz at the end of the activity for the user to complete	We will analyze the grades that the user's got (75% or above will constitute as successful)
Game-like design	Collecting data on how many items our game is used	This will show that our design is eye-catching to our users and promotes them to use our design to learn about the Webb Telescope	Our code will collect data on the amount of times our game is played	We will analyze the number of times that our game is used throughout exhibit
Easy setup	It takes less than 3 minutes to set up the project	Will show a well thought out set up	Measure personal difficulty	Whether or not there is struggle with set up process
36" x 28" when setup	The design measures to be 36" x 28" when setup of under	These are the specific numbers that the client requested for the design to be or under	We will use a ruler to measure	If the design measures to this constraint of below will constitute this criteria as successful
Safe	Measure the amount of injuries (0 injuries to determine it is successful)	Any injuries means that the project is in some way not safe to use	If any injury or destruction is reported or noticeable	Any number of 1 will constitute the criterion as failed
Total cost under $1000	The project bill is under $1000	This is the maximum amount that the client requested to be	We will keep track of the total amount that it will take to build this project	The bill of the project will constitute this as successful
Durability	Durable materials and good set up	Well constructed project	If anything is found broken or not	If nothing is broken and everything functions well

Peer Review Survey Results:

Id	Would you interact with this exhibit again?	Did you find this exhibit educational?	How difficult was it to accomplish the exhibit's goal?	Would you recommend this exhibit to a friend?
1	Yes	Yes	Too difficult	Yes
2	Yes	No	Too easy	Yes
3	Yes	Yes	Somewhat easy	Yes
4	Yes	Yes	Somewhat easy	Yes
5	Yes	Yes	Average	Yes
6	Yes	Yes	Somewhat easy	Yes

APPENDIX E - CODE USED IN PROJECT

ARDUINO CODE

```
/*
  Project 2
  Lawn of Gnomes
  3/19/24
  Model Telescope
  Photocell collects data from user input and prints to serial monitor
*/

const int analogInPin = A1; // Analog input pin that the photocell is
attached to
const int digitalInPin = 9; // Digital input pin that the button is
attached to
int buttonState = 0;
int outputValue = 0;
int sensorValue = 0;  // value read from the photocell
int SMin = 1023; // establish variables for min and max value of range
// Updated to be a high value so your calibration actually occurs
int SMax = 1023;

void setup() {
 Serial.begin(9600); // begin serial communication
   while (millis() < 1000) {
    sensorValue = analogRead(analogInPin);
    if (sensorValue < SMin){
      SMin = sensorValue;
      //Serial.println(sensorValue);
    }
 }
 pinMode(digitalInPin, INPUT);
}
void loop() {
  // Add a button that outputs a single character that MATLAB is looking
for. You can use that for starting and for a reset.
  buttonState = digitalRead(digitalInPin);
  if (buttonState == HIGH) { // when button is clicked
    Serial.println("B"); // print the letter B
  }
  // read the analog in value:
```

```
  sensorValue = analogRead(analogInPin);
  // map it to the range of the analog out:
  outputValue = map(sensorValue, SMin, SMax, 0, 255);
  // constrain the output value so it never goes beyond the limits
  outputValue = constrain(outputValue, 0, 255);
  // change the analog out value:
  sensorValue = analogRead(analogInPin); // read photocell input
  Serial.print("S:"); // print sensor value to serial monitor
  Serial.println(outputValue);
 // Serial.println(sensorValue);
  delay(200);
}
```

MATLAB CODE

```
%% Project 2 MatLab
% Lawn of Gnomes
% 3/19/24
% Model Telescope
% Takes data from Arduino and displays images from Webb Telescope

% Clean up commands
clc;
clear;
close;

%% Connect to the Arduino
% retrieve a list of available serial devices
 X = serialportlist;
% select the last device
 P = X(end);
% open serial connection to Arduino over that port
 ArduinoObj = serialport(P, 9600);

%% Create figure
fig = uifigure;
% set up figure window to fullscreen
fig.WindowState = 'maximized';
fig.Position = [0 0 1600 1000]; % THESE NUMBERS ARE SPECIFIC TO EACH LAPTOP
SCREEN RESOLUTION
% set up image on figure
im = uiimage(fig);
% set image to size of figure (fullscreen)
im.Position = fig.Position;
% choose image folder
folder = 'Clear';
```

```
% list of folder contents
fileList = dir(fullfile(folder, '*.jpg'));
titleScreen = imread("Screenshot 2024-04-09 160048.png"); % title screen image
im.ImageSource = titleScreen;
startScreen = imread("Screenshot 2024-04-09 163640.png"); % start screen image
timesUp = imread("Screenshot 2024-04-11 145900.png"); % times up screen image
niceJob = imread("Screenshot 2024-04-11 145653.png"); % nice job screen image
blackScreen = imread("download.jpg"); % black screen image

%% Run program
while(1) % start infinite loop
    ArdMsg = readline(ArduinoObj); % reads information from Arduino
    % disp(ArdMsg)
    if (contains(ArdMsg, 'B')) % IF message contains identifier 'B' THEN
        disp(ArdMsg)
        im.ImageSource = startScreen; % show start screen
        % get random number between 1 and number of items in image folder
        randomIndex = randi(length(fileList), 1, 1);
        % choose random image from folder using random number
        randomImage = fullfile(folder, fileList(randomIndex).name);
        % read random image from file
        image = imread(randomImage);
        ArdMsg = readline(ArduinoObj); % reads information from Arduino
        % Wait for light to shine
        SValue = 0;
        while SValue < 150 % while photocell value is less than 150, continue
to display start screen
            ArdMsg = readline(ArduinoObj); % read value
            SValue = sscanf(ArdMsg, 'S:%d');
            disp(SValue) % display value
        end
        disp("Starting scan") % display "starting scan"
    % end

        if (SValue > 150) % if photocell value is greater than 150
           pixelate = 10; % define pixelation value
           sz = size(image); % get image size
           blocksize = [pixelate pixelate]; % size of pixels
           % pixelate image
           outpict = imresize(image, round(sz(1:2)./blocksize));
           outpict = imresize(outpict,sz(1:2),'nearest');
           im.ImageSource = outpict; % display image to figure
           currentTime = datetime("now"); % define current time
            % while the time passed is less than 5 seconds
           while ((datetime("now") - currentTime) < duration(0,0,5))
               ArdMsg = readline(ArduinoObj); % read Arduino message
               SValue = sscanf(ArdMsg, 'S:%d'); % update sensor value
              if (SValue > 150) % check the value again
                if pixelate <= 1 % if the pixelation value is less than 1, end
the loop
                    pause(1)
                    break;
```

```
                end
                % decrease pixelation as the photocell keeps receiving light
                pixelate = pixelate - 0.7 ;
                blocksize = [pixelate pixelate];
                outpict = imresize(image, round(sz(1:2)./blocksize));
                outpict = imresize(outpict,sz(1:2),'nearest');
                im.ImageSource = outpict; % display unpixelated image
              % else
                 % im.ImageSource = outpict;

              end
             pause(0.00005);
           end
           im.ImageSource = timesUp; % display times up screen if pixel value
is not less than or equal to 1 after 5 seconds
        end
        if pixelate <=1 % if pixel value is less than or equal to 1
        im.ImageSource = blackScreen; % show black screen for 0.5 seconds (to
mimic taking a picture)
        pause(0.5);
        im.ImageSource = outpict; % show image again
        pause(1); % give user enough time to look at image
        im.ImageSource = niceJob; % display nice job screen
        end
    end
end
```

APPENDIX F - WIRE DIAGRAMS FOR ELECTRONICS

WIRE DIAGRAM FOR THE PHOTOCELL

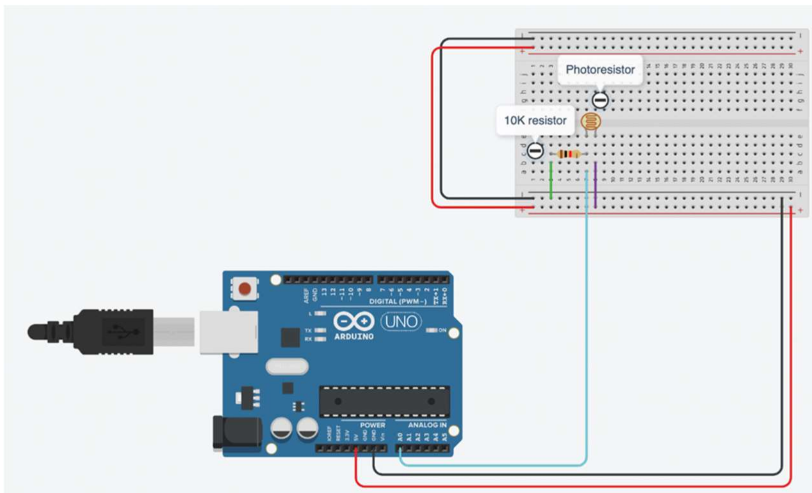


Figure 41. Wire diagram for Arduino photocell

WIRE DIAGRAM FOR THE BUTTON

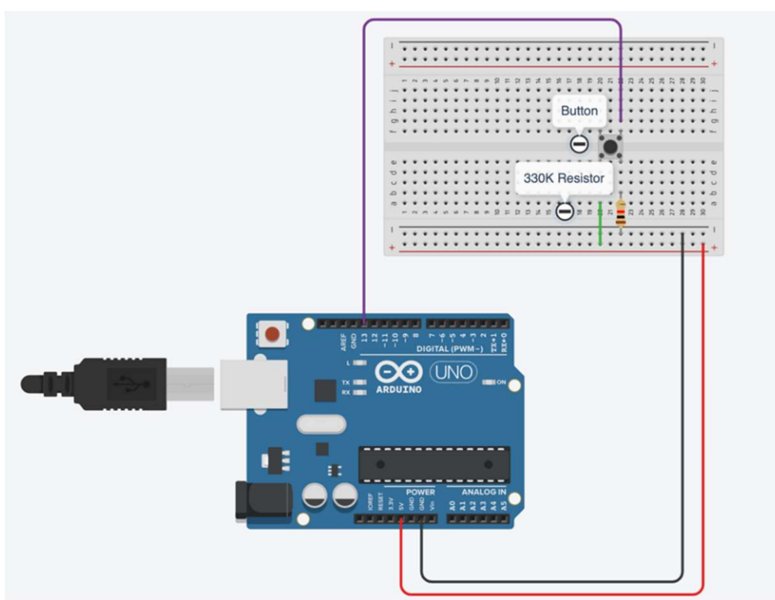


Figure 42. Wire diagram for Arduino button

APPENDIX G - PHOTO LOG

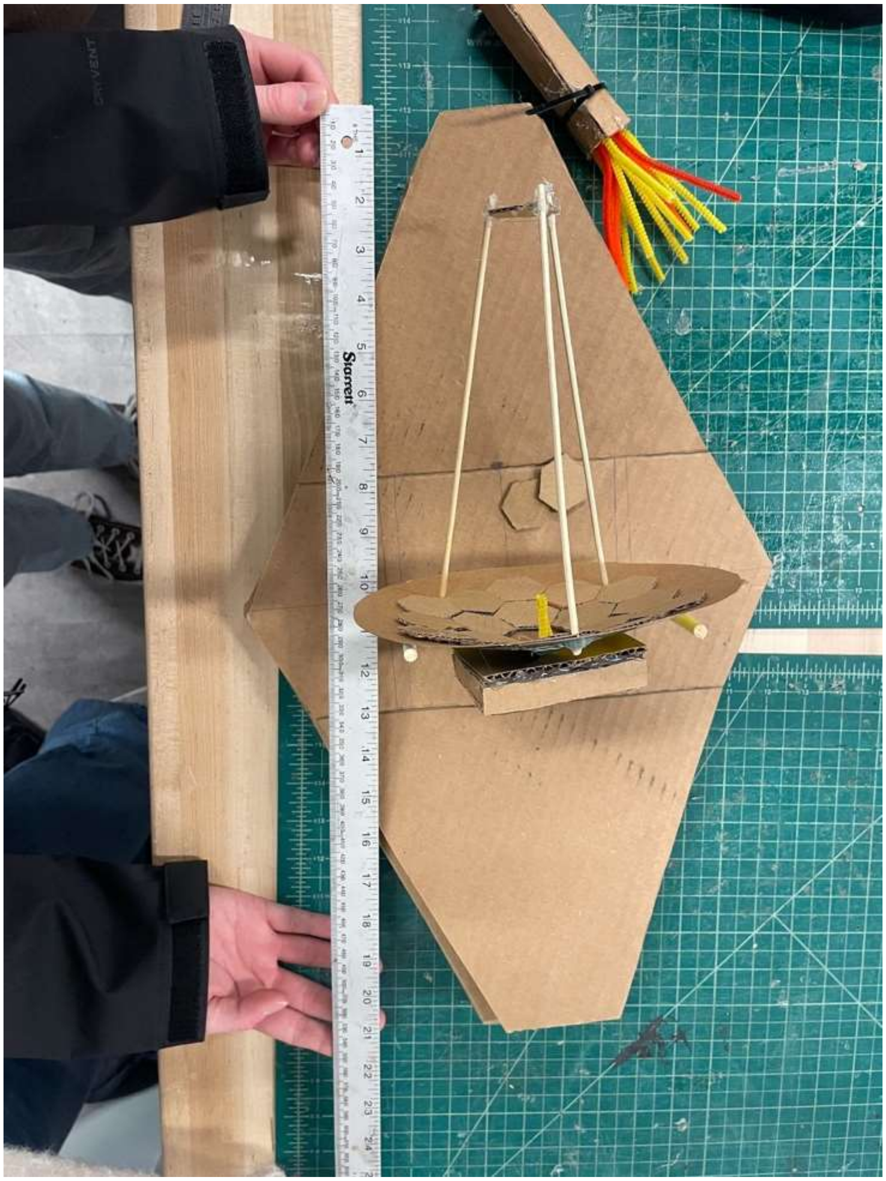


Figure 43. Top view of cardboard prototype from Milestone 3. Featuring base shape and primary mirror attached to secondary mirror and electronics box.

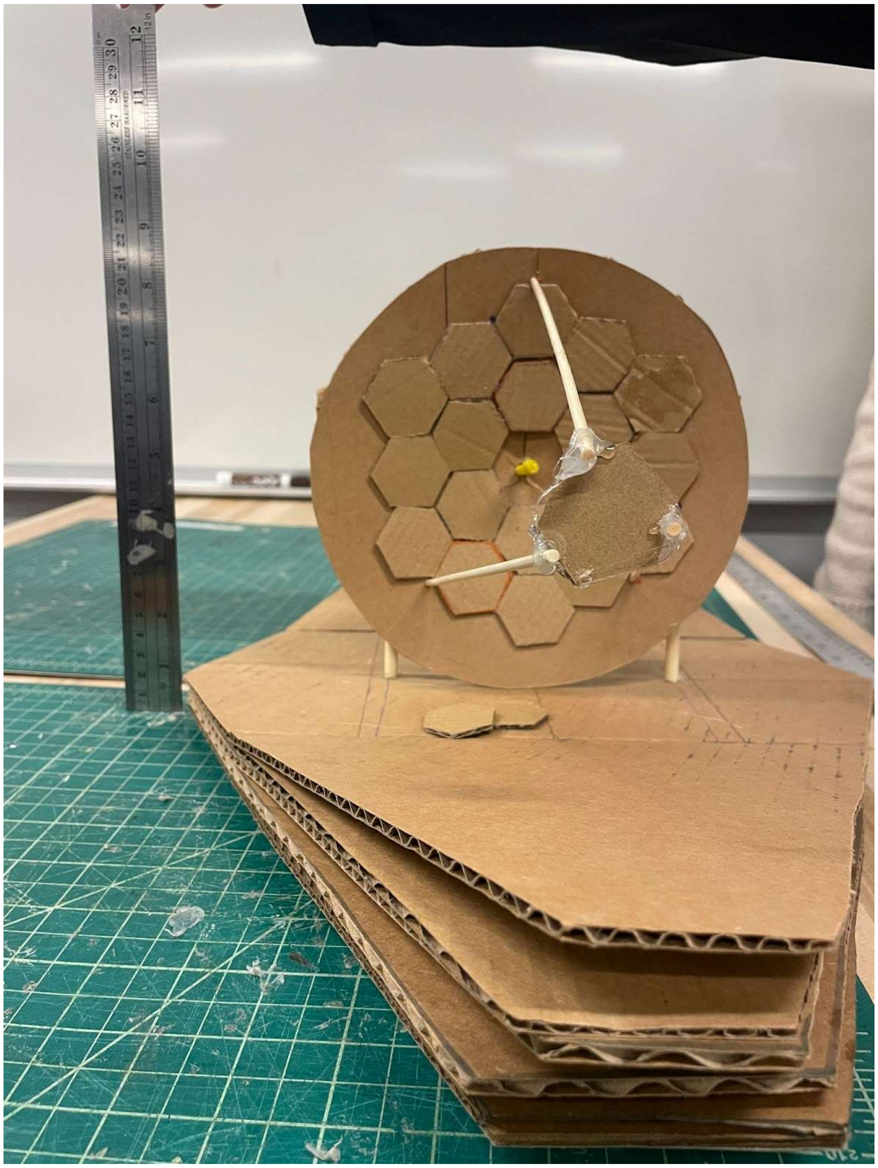


Figure 44. Front view of cardboard prototype. Featuring space in base layers and design of primary mirror.

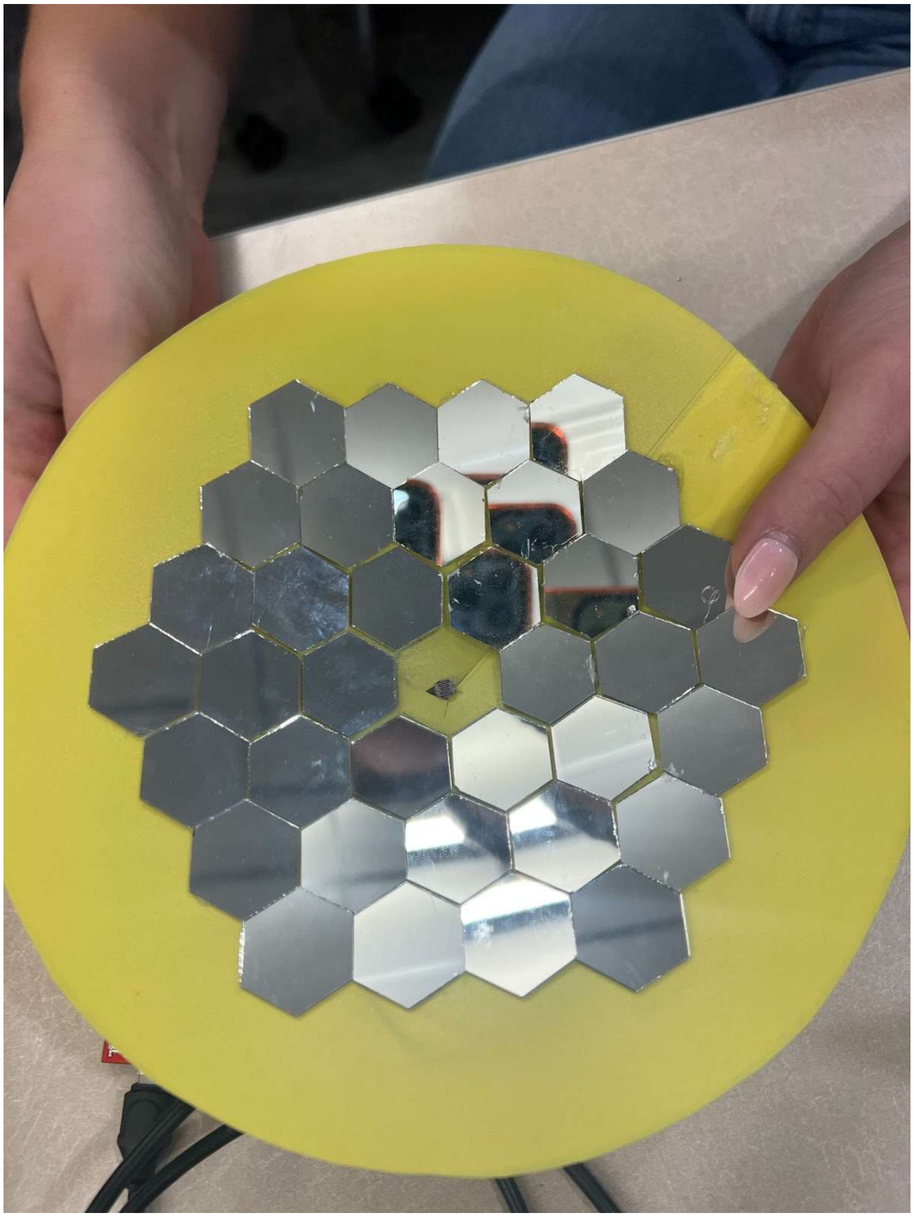


Figure 45. Initial design of primary mirror with photocell in the center, from Milestone 4.

Figure 46. Five base sheets of wood cut and ready to be assembled, Milestone 4.

Figure 47. Bottom of assembled base featuring the stand to help hid electronics, Milestone 5.

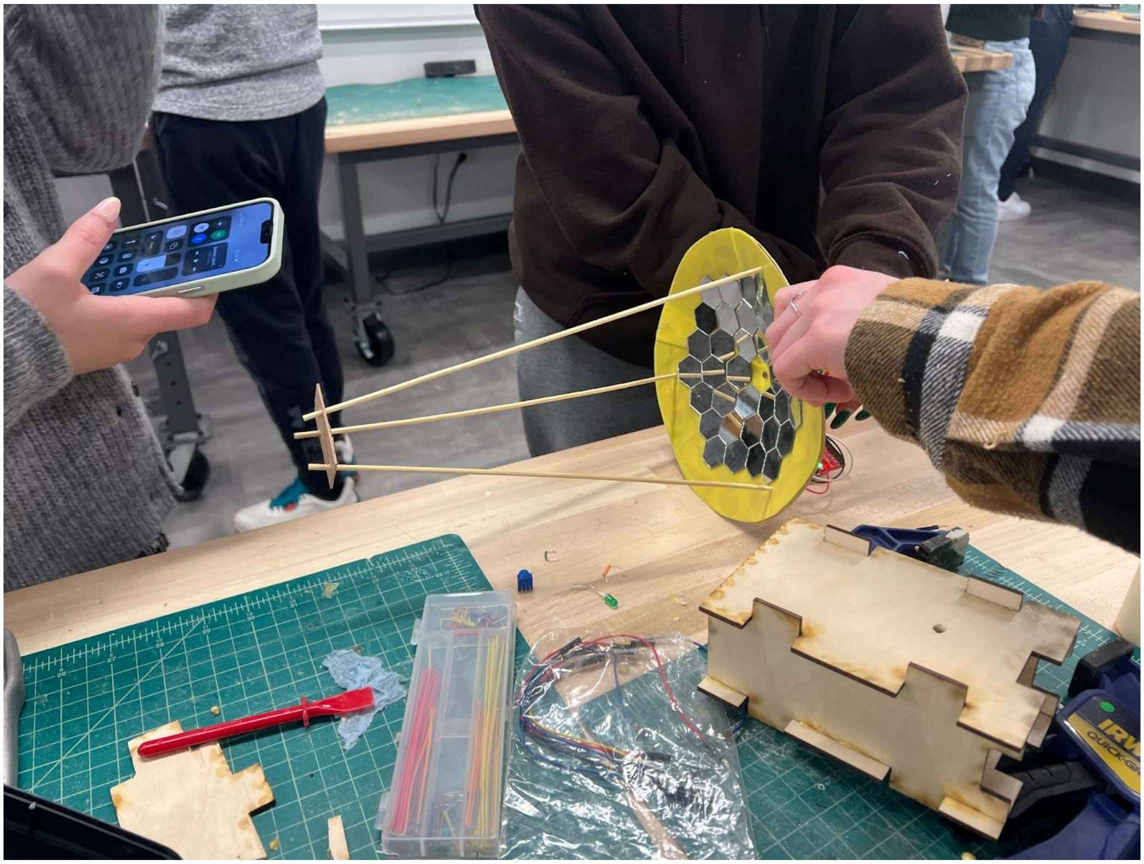


Figure 48. Set up of primary mirror and attachment of secondary mirror with wooden dowels, Milestone 5.

Figure 49. Assembly of two lasercut boxes. The right is a stand for the base of the model and the left is to house the electronics behind the primary mirror, Milestone 5.

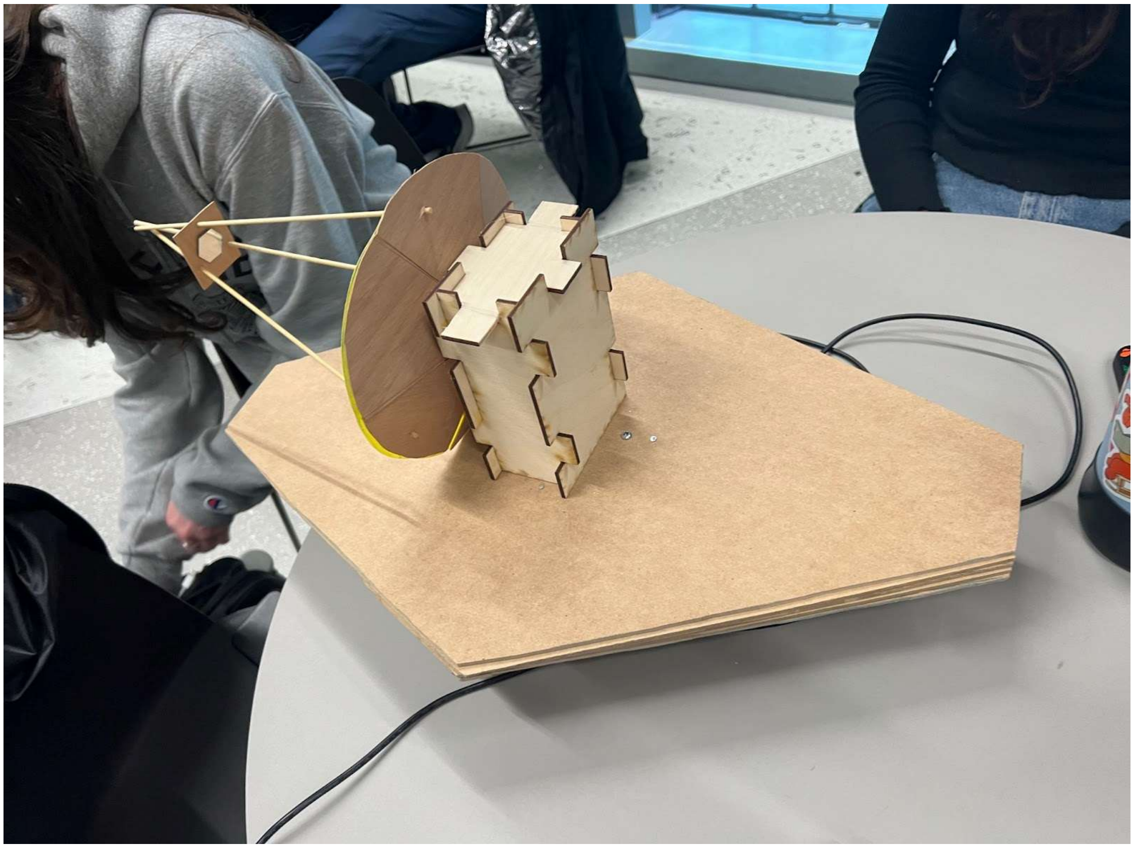


Figure 50. Back view of prototype (90% complete) for Milestone 5. Featuring electronics box attached to the back of the primary mirror.

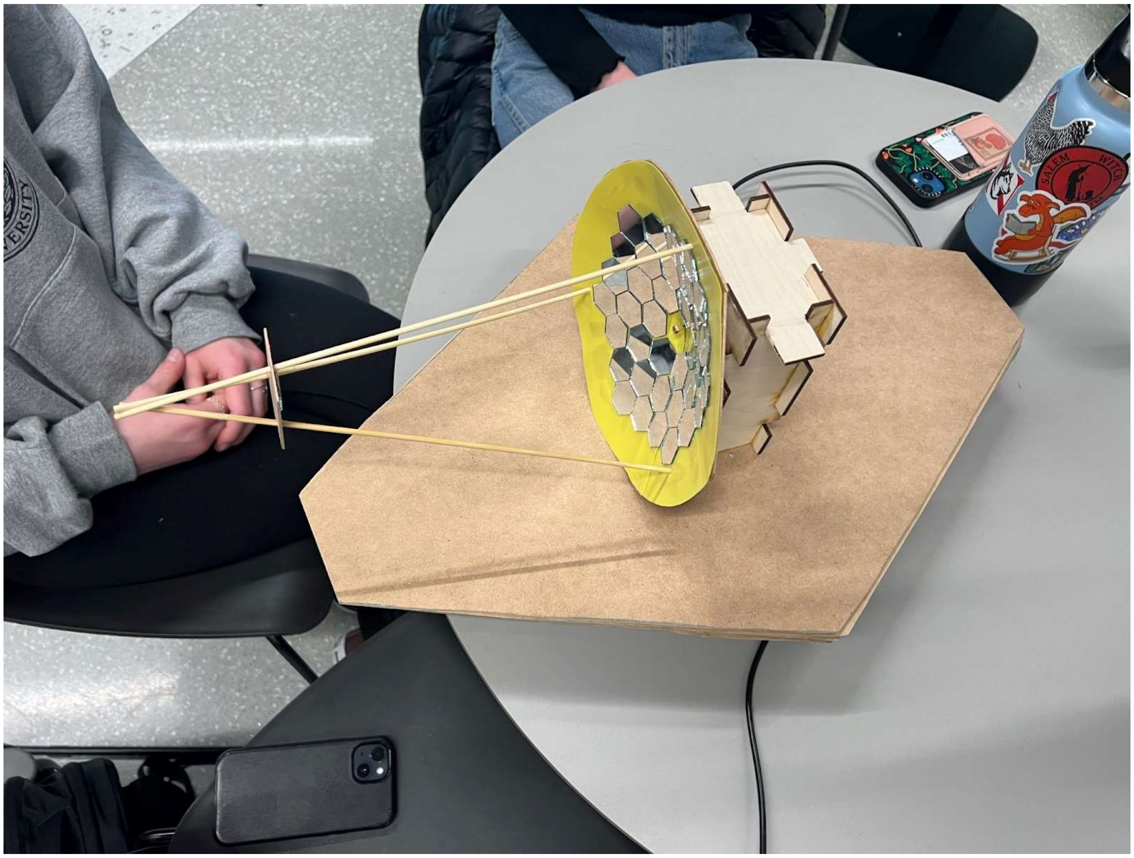


Figure 51. Front view of final for Milestone 5. Featuring the set up of the primary mirror.

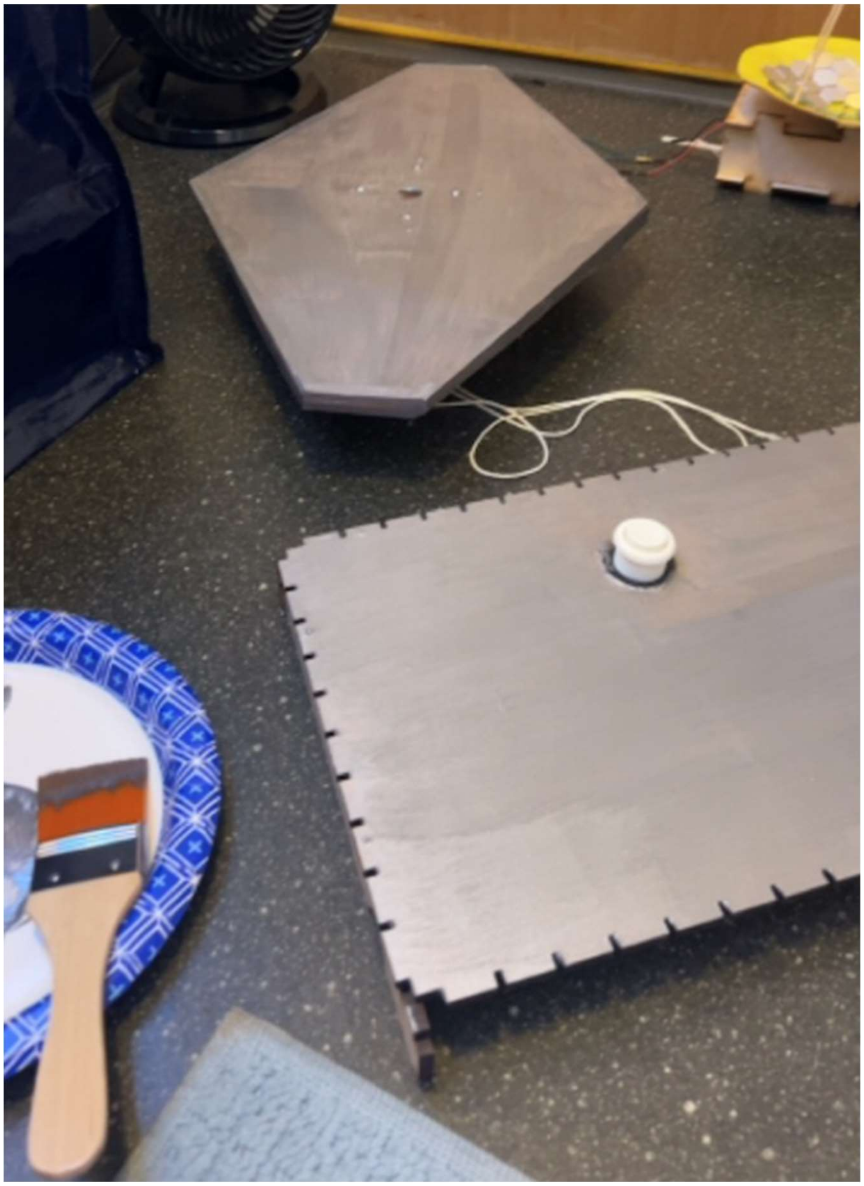


Figure 52. Painting the keyboard cover and base of the model during Milestone 6.

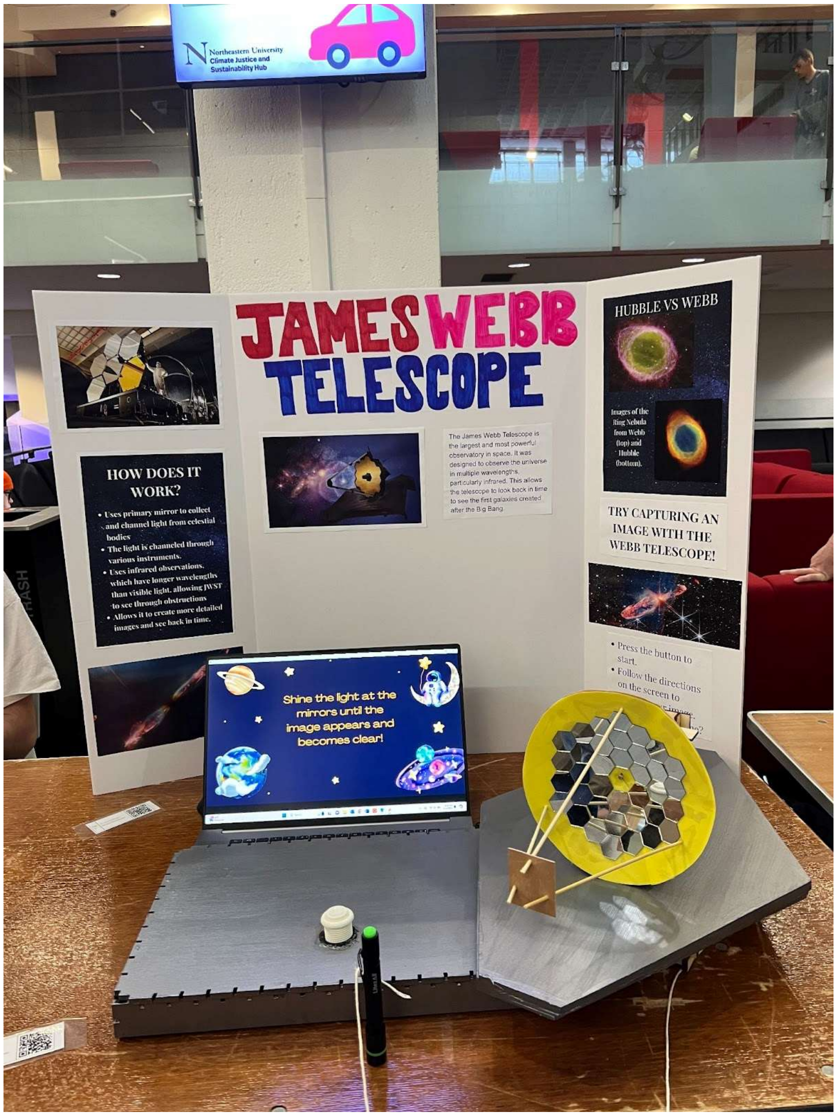


Figure 53. Final set up of our exhibit for the showcase at the end of Milestone 6. Featuring our model, laptop screen to display game, flashlight, keyboard cover, and informational poster.

APPENDIX H - GUI AND VISUAL LAYOUT

Title Screen

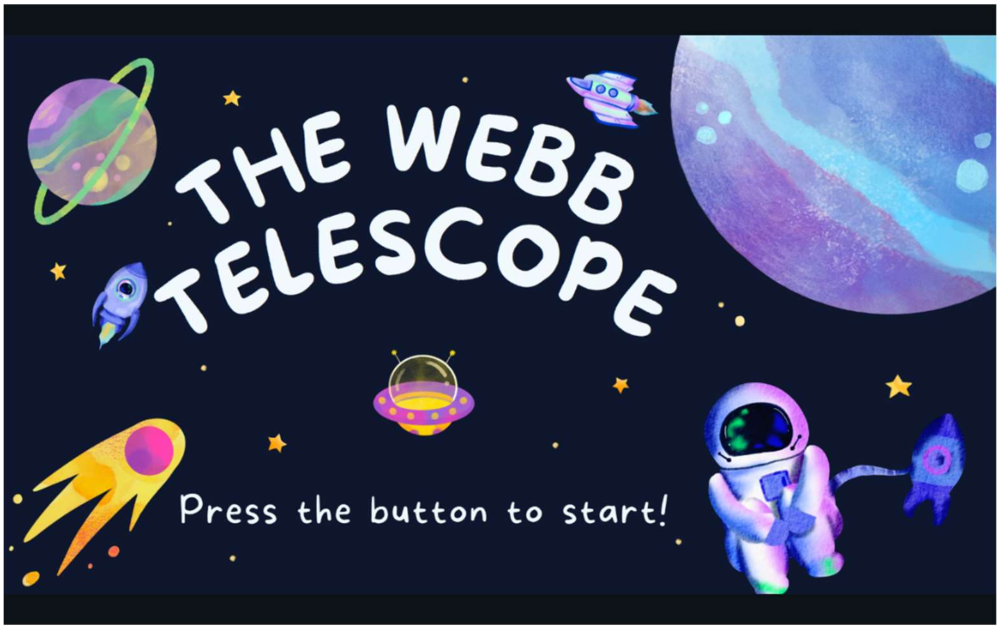


Figure 54. Initial title screen when code is run

Start Screen

Figure 55. Starting screen displayed when button is clicked

Time’s Up Screen

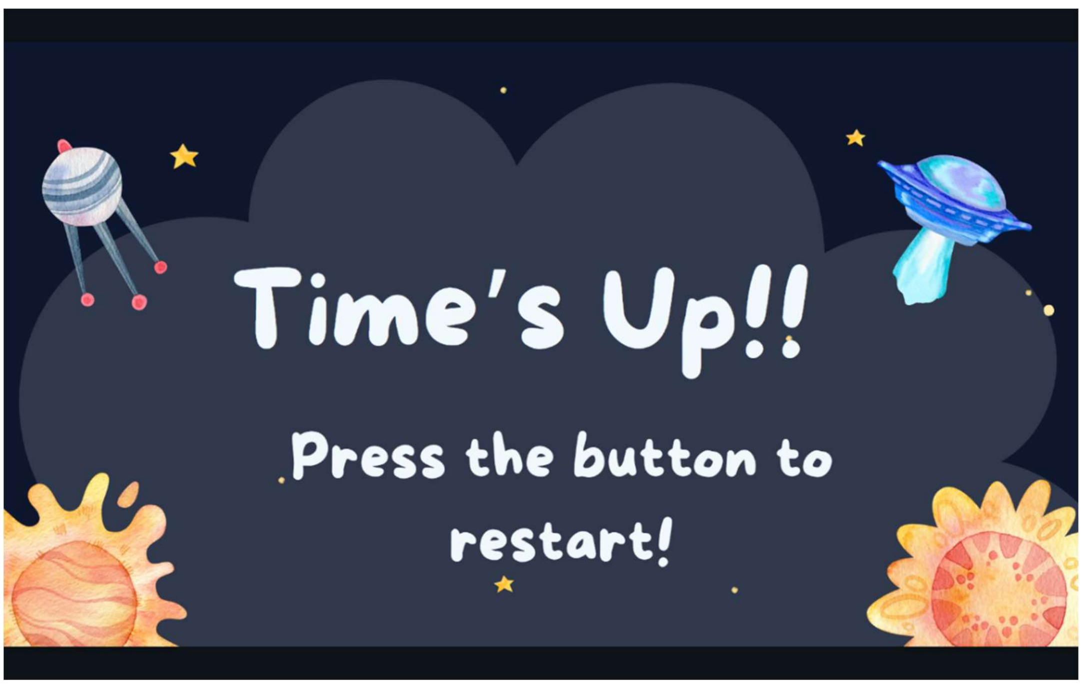
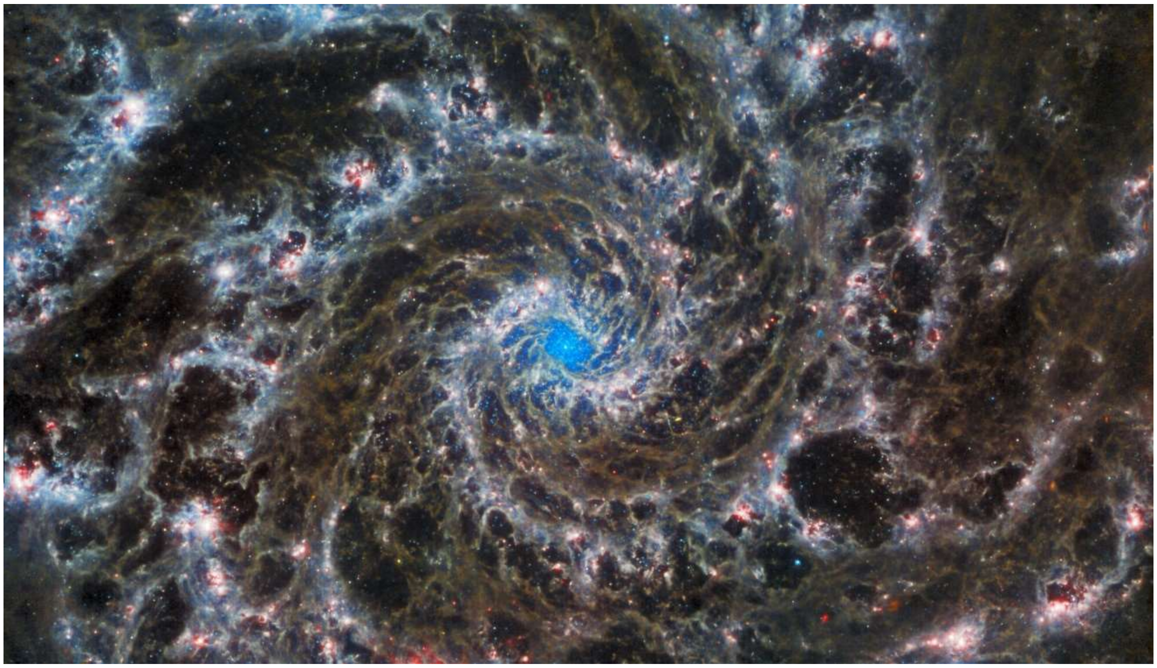


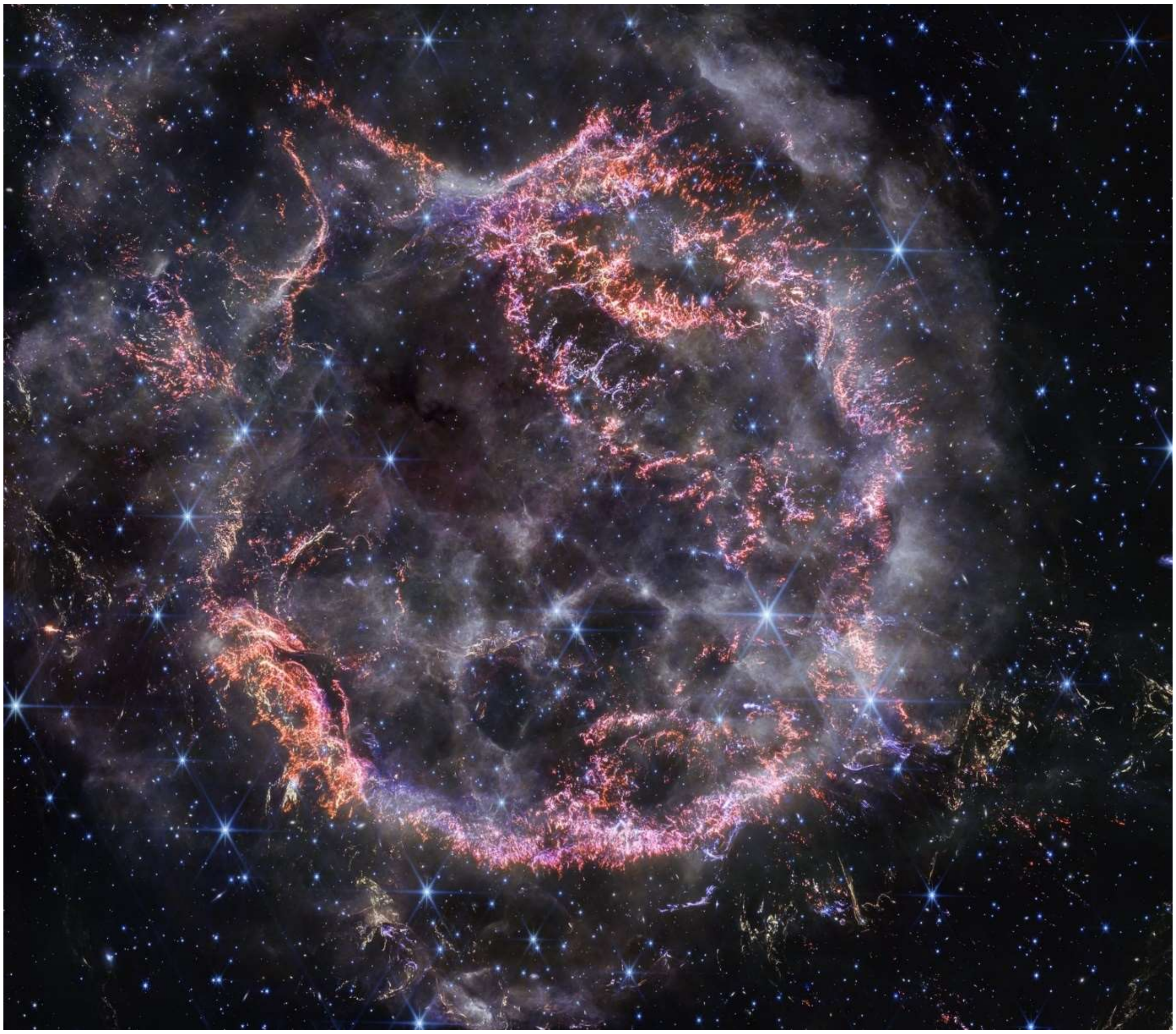
Figure 56. Image displayed if user runs out of time before image becomes clear

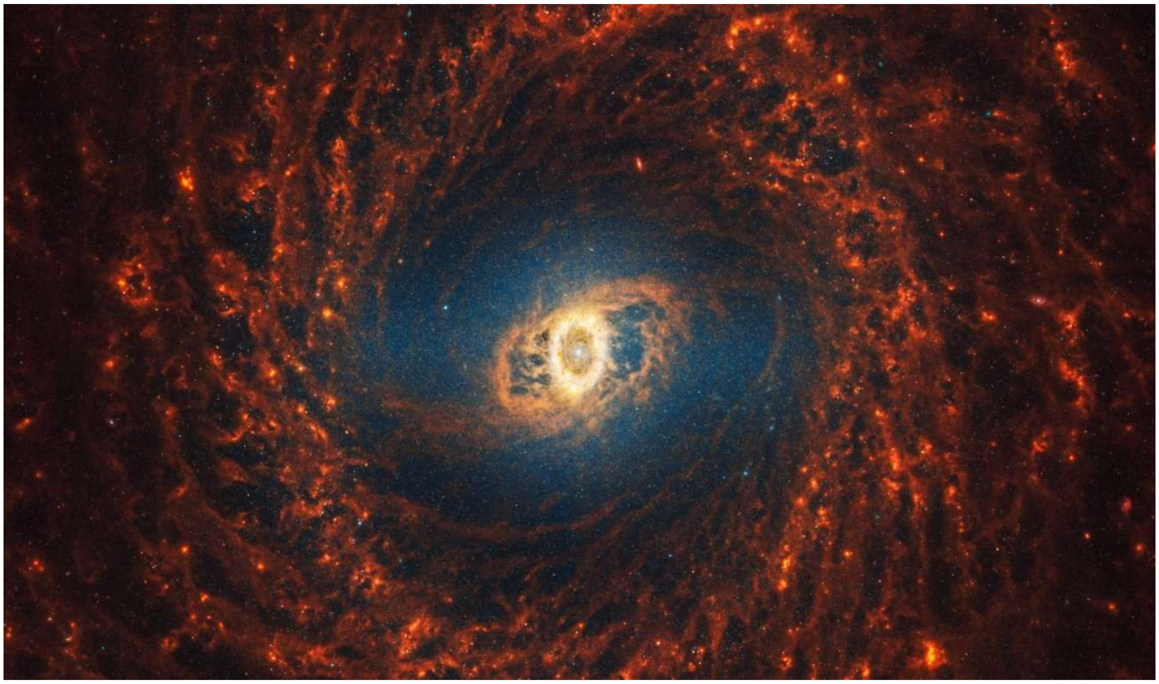
Nice Job Screen

Figure 57. Image displayed if user successfully pixelates the image in the 5 second time limit.

Webb Telescope Images







105

These images were all taken by the James Webb Telescope. They would randomly display on the screen with a larger pixel size if the user successfully reflected light onto the photocell. They would become clearer as the user successfully interacted with the model to become the images shown above. A variety of images were chosen to show the user the capabilities of the Webb Telescope and the full range of images it has taken.

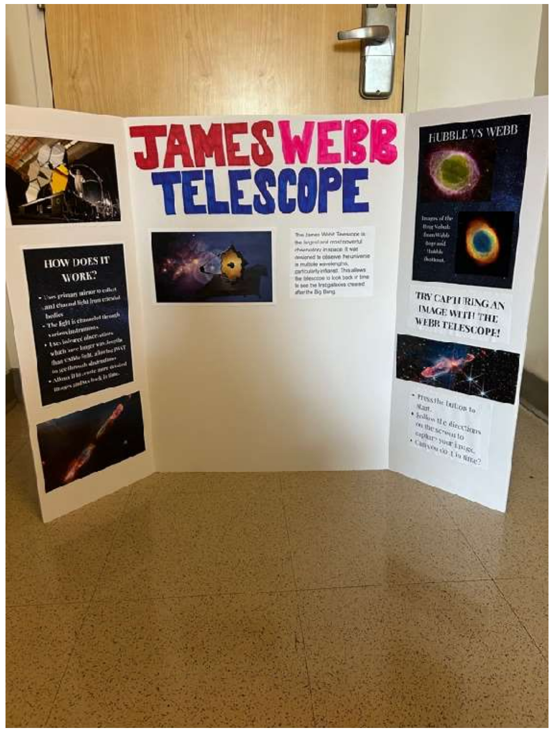
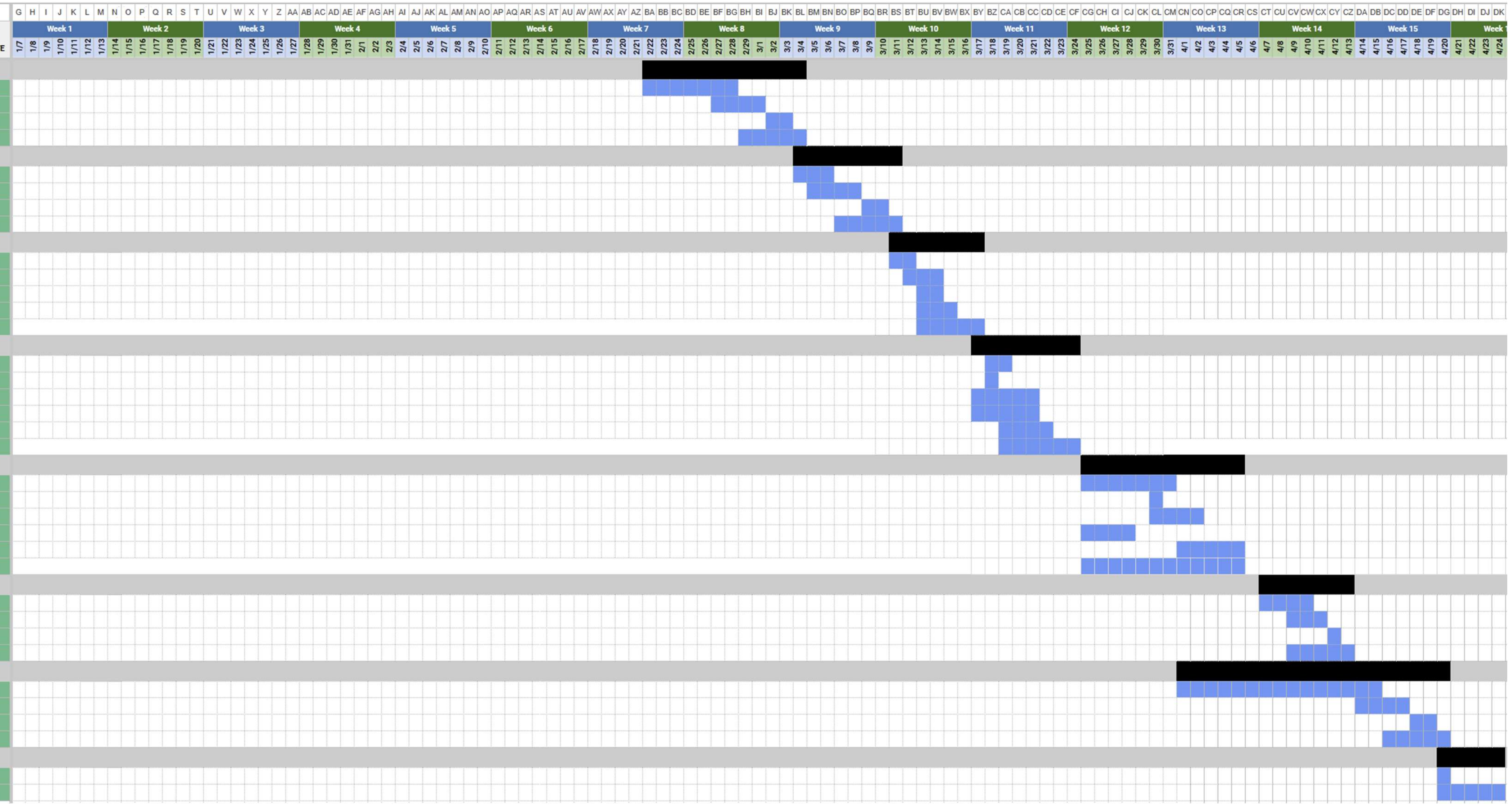


Figure 58. Completed poster board

APPENDIX I - FINAL GANTT CHART

	TASK TITLE	TASK OWNER	START	END	EXPECTED DURATION	PCT OF TASK COMPLETE
28	**P2-Milestone 1**	**PM 1**	**2/22**	**3/4**		**100%**
29	Project Planning	All	2/22	2/28	2hr	100%
30	Background Research	All	2/27	3/1	4hr	100%
31	Problem Statement	All	3/2	3/3	1hr	100%
32	Status Memo Writing	All	2/29	3/4	3hr	100%
33	**P2-Milestone 2**	**PM 2**	**3/4**	**3/11**		**100%**
34	Finalize Ideas	All	3/4	3/6	2hr	100%
35	Explore Alternate Solutions	All	3/5	3/8	2hr	100%
36	Mentore Meeting	All	3/9	3/10	1hr	100%
37	Status Memo Writing	All	3/7	3/11	3hr	100%
38	**P2-Milestone 3**	**PM 3**	**3/11**	**3/17**		**100%**
39	CAD drawings	All	3/11	3/12	2hr	100%
40	Cardboard Prototype	All	3/12	3/14	4hr	100%
41	Prepare Electronics	All	3/13	3/14	1.5hr	100%
42	Presentation Preparation	PS	3/13	3/15	2hr	100%
43	Status Memo Writing	PS,CR,AS	3/13	3/17	3hr	100%
44	**P2-Milestone 4**	**PM 4**	**3/17**	**3/24**		**100%**
45	Prototype Update	All	3/18	3/19	4hr	100%
46	Mentor Meeting	All	3/18	3/18	1hr	100%
47	Proof of Concept	All	3/17	3/21	2.5hr	100%
48	Evaluation Planning	All	3/17	3/21	2hr	100%
49	Presentation Preparation	RG	3/19	3/22	2hr	100%
50	Status Memo Writing	All	3/19	3/24	2hr	100%
51	**P2-Milestone 5**	**All**	**3/25**	**4/5**		**100%**
52	Evaluation Planning	All	3/25	3/31	2hr	100%
53	Mentor Meeting	All	3/30	3/30	1hr	100%
54	Design Review	All	3/30	4/2	2hr	100%
55	90% Complete Prototype	All	3/29	4/4	2.5hr	100%
56	Presentation Preparation	All	4/1	4/5	2hr	100%
57	Status Memo Writing	All	3/25	4/6	2hr	100%
58	**P2-Milestone 6**	**All**	**4/7**	**4/13**		**100%**
59	Finish Prototype	All	4/7	4/10	3hr	100%
60	Create Display Poster	All	4/9	4/11	2hr	100%
61	Client Demo	All	4/12	4/12	1.5hr	100%
62	Status Memo Writing	All	4/9	4/13	2hr	100%
63	**P2-Milestone 7**	**All**	**4/1**	**4/20**		**100%**
64	Prep Technical Report	All	4/1	4/15	2hr	100%
65	Write Technical Report	All	4/14	4/17	15hr	100%
66	80%	All	4/18	4/19	1hr	100%
67	Peer Feedback	All	4/16	4/20	12hr	100%
68	**P2-Milestone 8**	**All**	**4/20**	**4/24**		**100%**
69	Review Peer Feedback	All	4/20	4/20	2hr	100%
70	Complete Technical Report	All	4/20	4/24	8hr	100%



APPENDIX J - FINAL BUDGET

Item	Unit Value	Units	Qty	Value	Cost	Source	MFR PN/Link	Notes
Breadboard	$5.50	ea	1	$6	$0	SparkFun Kit	Breadboard	
RedBoard	$21.50	ea	1	$22	$0	SparkFun Kit	RedBoard	
Wires	$2.45	pk	1	$2	$0	SparkFun Kit	Wires	
LED Lights	$0.60	ea	3	$2	$0	SparkFun Kit	LED	
Photocell	$1.60	ea	1	$2	$0	SparkFun Kit	Photocell	
330 Resistors	$0.30	ea	3	$1	$0	SparkFun Kit	330	
10k Resistors	$0.50	pk	1	$1	$0	SparkFun Kit	10k	
USB Cable	$1.98	ea	1	$2	$0	SparkFun Kit	USB	
Poster	$10.34	ea	1	$10	$10	Walmart	Tri-fold Board	
Markers	$5.76	pk	1	$6	$6	Amazon	Broad Line Markers	
Photo - Printing	$0.10	ea	5	$1	$0.50	Library		
Hot Glue Gun	$9.97	e	1	$10	$0	FYELIC	Glue Gun	
Hot Glue Sticks	$7.99	pk	1	$8	$0	FYELIC	Glue Sticks	
Mirror Tiles	$14.99	pk	1	$15	$15	Etsy	Mirror Mosaic Tiles	
Wood Boards	$14.94	ea	2	$30	$0	FYELIC	Wood	
Screws	$9.97	pk	1	$10	$0	FYELIC	Screws	
Wood Glue	$3.97	ea	1	$4	$0	FYELIC	Wood Glue	
Wooden Dowels	$5.99	pk	1	$6	$0	FYELIC	Dowels	
Monitor	$79.99	ea	1	$80	$0	Gnomes	Monitor	We will be using our own computer
Flashlight	$6.99	ea	1	$7	$7	Amazon	Flashlight	
Folder	$5.99	pk	1	$6	$0	Gnomes	Folder	
Wood	$10.99	ea	2	$22	$22	Bookstore		
Long Wood	$5.52	pk	2	$6	$6	EXP Makerspace		

Thin Plywood	$5.48	ea	1	$5	$0	Professor O'Connell	Wood	
Paint	$12.34	ea	1	$12	$12	Blick		
Paint brushes	$6.23	pk	1	$6	$6	Blick		
Button	$2.90	ea	1	$3	$0	Professor O'Connel		
			Totals	$285.00	$84.65			

APPENDIX K - PROJECT HOURS LOG

	Aashna Sahani	Carly Robinson	Piper Schmdt	Rain Gatrell
Milestone 1				
Individual Background Research	1	1.5	1	1
Group Meeting to Formulate Problem Statement	1	1	1	1
Presentation Preparation and Group Status	0	2.5	0	0
Memo	1	1.5	0.5	0.5
MS1 Totals	3	6.5	2.5	2.5
Milestone 2				
Individual Solution Generation	1.5	1.5	1.5	1.5
Meeting with Mentor	1	1	1	0
Presentation Preparation and Group Status	2	0	0	0
Memo	2	2	2	0
MS2 Totals	6.5	4.5	4.5	1.5
Milestone 3				
AutoCAD Sketches	1	1.5	1	1
Prototype Building	3	3.5	3	1.5
Presentation Preparation and Group Status	0	0	2	0
Memo	2	1.5	2.5	1
MS3 Totals	6	6.5	8.5	3.5
Milestone 4				
Evaluation Planning	1.5	1.5	1.5	1

Concept Build/Electronics	3.5	3	3.5	3
Presentation Preparation and Group Status	0	0	0	2
Memo	1,5	1.5	1.5	2
MS4 Totals	6.5	6	6.5	8
Milestone 5				
Prototype Building	4.5	4	4.5	4
Meeting with Mentor	0	1	1	1
Gallery Walk	1	1	1	1
Memo	1	1	1	0
MS5 Totals	6.5	7	7.5	6
Milestone 6				
Finish Building the Project	7	5.5	5.5	1
The Event	2	2	2	2
Memo	0	0.5	0.5	3
MS6 Totals	9	8	8	6
Totals	37.5	38.5	37.5	27.5

APPENDIX L - DECISION ANALYSIS

Rank Order:

	Interactive/ Game-like	Educational	Easy set up/Portability	Attainable/ Realistic design	Durability /Safety	Total
interactive/ game-like	X	0	1	-1	-1	-1
educational	0	X	1	-1	-1	0
Easy set up/ Portability	-1	-1	X	-1	-1	-4
attainable/realistic design	1	1	1	X	-1	3
Durability/Safety	1	1	1	1	X	4

Table 1. Rank Order Chart

We compared each characteristic and chose which we felt was more important to have in our final design if we were unable to have both. We chose these five categories because we felt they were all critical to consider in our final design but imagined a drastic situation where we needed to choose one over the other when completing this rank order chart to assign weights to each one.

Kepner-Tregoe Decision Analysis:

Goals	Durability/ Safety	Attainable/ Realistic design	Educational	Interactive/ Game-like	Easy set-up/ Portability	Totals
Weights	10	9	7	6	2	
Model Telescope	7/70	8/72	10/70	7/42	6/12	266
Dial	9/90	7/63	8/56	6/36	8/16	261
Button+image	9/90	7/63	7/49	6/36	7/14	252
Camera	9/90	6/54	6/42	8/48	7/14	248
Image Dial	9/90	4/36	6/42	6/36	10/20	224

Table 2. Kepner-Tregoe Decision Analysis Chart (KTDA Chart)

After we assigned weights to each category using our rank order chart, we rated each design idea on a scale from 1 to 10 in each category. A 10 in durability/safety meant no exposed electronics, all durable materials, and no fragile parts while a 1 meant exposed Redboard, and many fragile parts intricately connected. A 10 in attainability meant we felt confident in all required electronics and building procedures and a 1 meant we felt confident in none of the electronics and building procedures. A 10 in education meant we felt it was a unique and creative way to convey a lot of information and a 1 meant the information would not get across as well. A 10 in interactive meant the design was game-like with a unique user interface and a 1 meant the design was not game-like at all with no user interface. A 10 in portability meant the design was one-piece, light weight, and small, while a 1 meant the design was heavy, large, and many different pieces. Using these criteria, the model telescope came out with the highest score of 266.