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WIND TURBINE CREATOR

SUBMITTED BY:

Team 4

PREPARED BY:

Leo Norton
Rory O'Neill
Austin Philp

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Abstract

Wind turbines have been used since ancient times to effectively utilize wind energy. In our current day we are racing to replace fossil fuel sources with renewable energy sources, the next generation of engineers need to be inspired to work in important sustainability fields. This paper details the engineering process behind a "build and test your own wind turbine" museum exhibit. We were presented with the problem of how we could inform children about wind turbines and renewable energy in an engaging and entertaining way. Our solution was to create an exhibit that inspires open-ended creativity while also teaching about different turbine designs through hands-on experimentation. The elementary aged students would be able to construct a wind turbine rotor through modular parts and place it in a small wind tunnel to test it. The hope was that we could engage young students by giving them freedom and having faith in their competence. Our constraints included a $100 budget and the portability of our exhibit. Our exhibit was shown to be a success. Not only did we keep within our constraints budget and size restraints, we also had great viewer engagement while teaching through hands-on learning, critical thinking skills, and testing knowledge.

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LEO NORTON

1. INTRODUCTION

With the advent of the climate crisis rapidly becoming the most pressing issue of our generation, it's more important than ever to work towards switching our fossil-fuel-based energy sources to renewable energy sources. Wind power is an increasingly important source of renewable energy that engineers are utilizing more and more.

When working to inspire a new generation of engineers in the topics of sustainability, we decided to focus on teaching about wind turbine design, and the general mechanisms of wind turbines.

In the work to design wind turbines, a multitude of engineering design challenges need to be tackled. The location, size, and general construction of turbines are all important crucial elements to wind turbine design. During the ideation phase of our project, we decided that the most easily understandable element of turbine construction was blade design. For this reason, we decided to frame our educational exhibit around types of wind turbine blades and their design.

We decided to create a museum exhibit project in which the user can build a set of wind turbine blades based on a simple peg-construction system. The user will then be able to test their wind turbine in a small wind tunnel and learn from the performance of their design.

1.1. PROBLEM STATEMENT

The problem is that many young students aren't familiar with different wind turbine designs past the classic three-blade turbine. They also aren't engaged with the topic of renewable energy generation. This is important because this new generation will need to focus on the problem of sustainability in their future work. Currently, there are exhibits surrounding wind turbines but they aren't hands-on or engaging enough to capture the attention of elementary-age students.

The users need a design that is immediately engaging and focused on creativity while teaching them about the topic at hand. Our solution will be an exhibit that inspires open-ended creativity but also needs to emphasize teaching about different turbine designs. This will include hands-on experimentation and will actively engage young students by giving them freedom and having faith in their competence. Our constraints include a $100 budget and the portability of our exhibit.

1.2. Stakeholders

The main shareholders in our project are our team, the users, and our clients. In this case, I am considering our clients to be the users teachers and our teacher and TAs. Our team includes me, Austin Philp, and Rory O'Neill. Our users will be fourth and fifth grade students. Our project will be shown at a Northeastern expo for these elementary schoolers and must be designed to accommodate kids of this age. Our teacher, KSG and our TAs would be considered our clients, as they need our projects to be high quality and informative to remain in good standing with the elementary school. The teachers of the elementary students would also be considered our clients as we need to keep the elementary schoolers engaged while teaching them about sustainability.

1.3. Project Constraints

We have multiple main project constraints to consider in the design and construction of our museum exhibit. Above all, the project has to be safe for elementary school students to play. For a wind tunnel, this mainly means keeping their hands out of any spinning blades. Apart from safety, we also have to design our project to fit in specific dimensions; we need to be able to build our project within a certain budget; it needs to teach the user about sustainability topics effectively; and it needs to keep kids engaged.

1.4. Pertinent Topics

1.4.1. Wind turbine Design

The field of wind turbine design has a multitude of considerations when it comes to turbine type. I feel that talking about blade aerodynamics and fluid flow is beyond the scope of this project. I will cover the design decisions around choosing a wind turbine type to build. The turbine types are mainly divided into two categories, horizontal-axis wind turbines (HAWT) and vertical-axis wind turbines (VAWT). This designation refers to the orientation of the axis of revolution of the turbine to the ground (see Section 2.2 for more details).

In our museum exhibit we have three HAWT turbines which can be constructed from our modular parts. A single-blade turbine, a two-blade turbine, and a triple-blade turbine. Our project can also be reconfigured to construct and demonstrate a Savonius VAWT turbine.

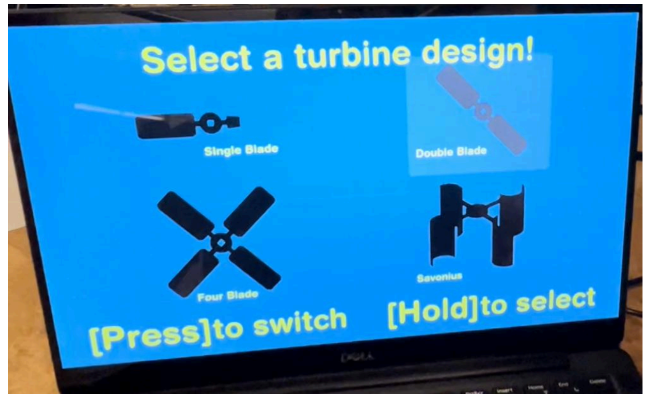


Fig. 1.00. “Wind Turbine Selection Screen”

Each of these turbines have different upsides and downsides in the real world which will be explained in our exhibit [1].

1.4.2. Lego Creator Theme

The artistic theming for our project is centered around Lego, specifically the Lego Creator line of products. We feel that this theme fits our project, as we have created a modular building system with some similarities to Lego. This meeting will hopefully more quickly engage kids with our project.

1.5. Scope

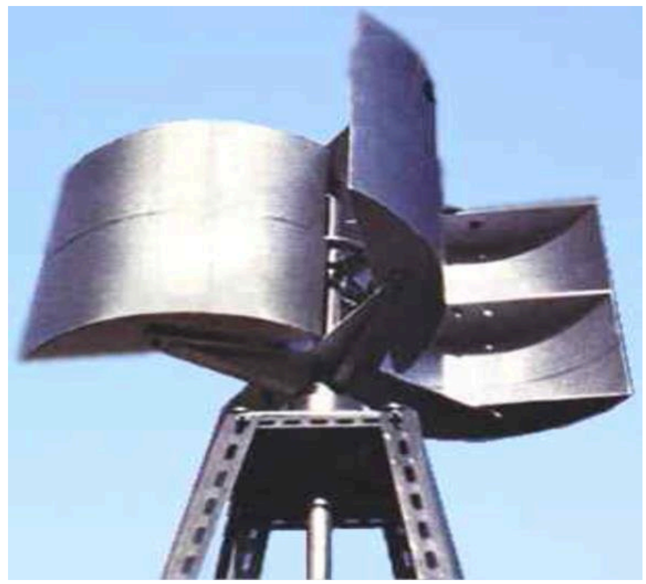
This project will be constructed using simple ¼” plywood with many 3D printed elements. The project will run autonomously, and will be able to be used by multiple users in a row, completely resetting each time. Instructions on how to use the exhibit will be issued through a monitor playing a Unity game. We plan to have five different buildable wind turbine variations which the user can then configure to make a multitude of creative designs.

2. Background

2.1. History of Rotor Design

Wind turbines and mills have been used since ancient times to do work for various applications. Windmills, or devices which use wind power to grind grains, are extremely old technology. In ancient China, wind powered devices have also been used to do tasks like pumping water to higher elevations.

During the 19th and 20th century, small electricity generating wind turbines began to be used. The first of these wind turbines were simple wooden horizontal axis turbines with many blades. Limited construction means and lack of innovation and aerodynamic understanding meant that these turbines were quite inefficient and had high drag. Many additional blades were also added to these turbines which increased material costs and weight but increased power output for these specific, low efficiency cases. Vertical axis, Savonius-style wind turbines were also commonly built early on due to how easily one can construct them. Since the turbine sits on a level, the structure backing the axis doesn't have to be extremely enforced like in the case of a horizontal axis wind turbine.



|Fig. 1.01. "Savonius Wind Turbine"

In the 1930's, wind generators began to attain widespread usage as a way to get electricity to remote places. In the 1970's the US government began their campaign of incentivising wind turbine research with the goal of replacing fossil fuels for sustainability. By 2021, globally, more than 1,808 billion kWh of wind energy had been generated.

With the goal of total global replacement of fossil fuels in as near a future as 2030, we need more engineers in the field to be interested in sustainability topics and engineering for renewables [4].

2.2. Wind Turbine Types

The two overarching wind turbine types are vertical axis wind turbines (VAWT) and horizontal axis wind turbines (HAWT). This refers to whether the axis of the rotor is vertical or horizontal compared to the ground.

VAWTs are less efficient than HAWTs but are more advantageous in some scenarios. Their main advantage is that they can receive wind from any angle. In other words, they don’t have to be pointed into the wind in order to function. Because of this, these wind turbines are better for urban settings where the wind direction can change fast.

VAWTs are usually either Darrieus, Helical, or Savonius type turbines. Our museum exhibit only used Savonius, or drag driven wind turbines. This means that the cup or curved panel which receives wind creates drag which drives the rotor. This is in contrast to Darrieus or turbines which use lift to drive the rotor. Darrieus turbines are commonly shaped like large egg beaters, with two large curved wings capturing wind using lift. Helical turbines look like spirals, and use lift and drag as the wind gets caught in the concave portion of the turbine and moves up the screw-like shape.

Fig. 1.02 “Darrieus Wind Turbine”

Savonius turbines work better than other VAWTs at small scales. This is why they were used for our exhibit [2].

2.3. Major Design Considerations

There are several major design elements to consider when designing a wind turbine in the real world. Location, size, material cost, and efficiency all have to be taken into account when choosing and designing a full turbine.

Blade length is the biggest factor in determining the electricity output of the turbine. Some HAWTs have blades up to 100 ft long. Smaller, three-blade wind turbines can generate around 10kW while larger turbines can generate up to around 15MW(15000kW) of power [1].

Overall, more blades result in greater aerodynamic efficiency. There is a certain point where more blades stop becoming advantageous due to a large moment of inertia of the rotor. Few blades don’t catch the wind as well but have better overall aerodynamics. With well designed blades, laminar flow of air is created across the wing which decreases drag.

Single blade turbines, while not efficient, are very aerodynamic designs. This makes single blade turbines much quieter than turbines with more blades and therefore more desire around where people live. Many complain about the annoying sound generated by turbines with more blades. Due to their asymmetry, single blades are not as aesthetically pleasing to most people.

|Fig. 1.03 “Single Blade Turbine”

In order for wind turbines to be effective, public perception of them must be good. Design considerations such as aesthetics, sound, and annoying flicker effects are very important factors. Three blade turbines usually have the greatest public appeal. They are aesthetically pleasing, somewhat loud, but don’t create annoying flickering patterns [3].

3. Methodology

3.1. Problem Definition

We spent a lot of time defining the problem we solved with our project. Our main mission was to engage youth in order to inspire a new generation of engineers. We thought that many museum exhibits ideas weren't tactile enough, or didn't have enough hands-on elements to fully keep young children engaged. We also felt that elementary aged kids' competence is often underappreciated. Our exhibit aimed to put faith in the competence of the kids by giving them a somewhat more challenging task.

Creativity was also a necessity in our exhibit design. To fully engage the young students, we felt that some aspect of the system should inspire creativity, or there should be multiple ways to solve the problems presented in the exhibit.

We also decided to focus our exhibit on a more niche topic that wouldn't be done by other groups and that elementary schoolers wouldn't know much about.

Finally, we focused on creating an exhibit that felt like a game to play. We wanted there to be a somewhat competitive aspect as well as a lot of replayability. Users won't engage in a boring product. Prioritizing fun in an exhibit is important.

3.2. Solution Generation

Throughout our solution generation phase, we used multiple techniques to quickly start coming up with ideas. We used a 3-3-2 brainstorming technique, in which the three of us wrote down three ideas each on sticky notes and passed them around to quickly get two pieces of feedback on each idea. Through this feedback system, we were able to quickly come up with a couple ideas such as an energy grid modeling game, water purification demonstration, electric vehicle racing game, and the wind tunnel exhibit.

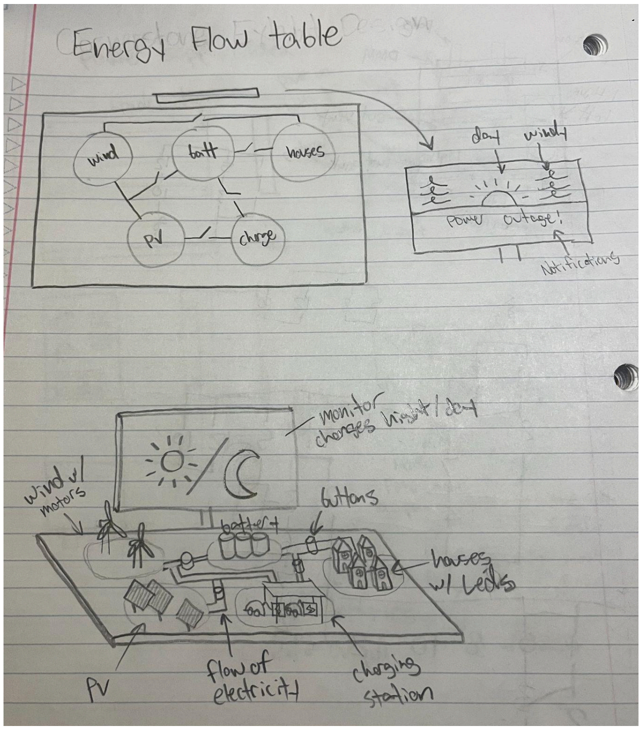


Fig. 1.04 “Energy Flow Table Idea”

We made multiple sketches of our solution ideas and iterated on these ideas, evaluating what was feasible, what was entertaining, and what was impractical.

We used the “fresh perspective” brainstorming technique as well, querying our friends and classmates about what they would find fun in an exhibit. During our mentor meeting with TJ, we came up with more design solutions and talked about how various problems with our ideas could be solved.

3.3. Deciding on a Solution

In the end, there was a clear winner in our solution ideas. We decided to pick the “wind turbine design game” as it was practical, fun, creative, and extremely hands-on.

Immediately, the wind turbine design can be understood. The simple and visual construction of a turbine should be easy to understand by young students. In addition, we felt that having the ability to physically create a wind turbine from parts would be extremely engaging. During our mentor meeting, he stated that the wind turbine tunnel idea would be like “Complementing them [the user] on a subconscious level that you trust them enough to create a turbine”.

Finally, the solution was easy to implement, as it required relatively few complex components. It had no need for a driver IC, complicated display system, or an additional microcontroller. We felt that the design idea had a large “bang for your buck”. The most complex aspect of the system was arguably a modular turbine assembly system which would need to be designed with care but could be easily 3D printed.

Peer feedback on the design was also very positive. People felt that the idea was overall fun. We were encouraged by the fact that our peers quickly wanted to play with the parts we were prototyping.

We created a KTDA decision analysis chart with all of our main ideas on it (See Appendix C). The wind turbine design game won by a margin of over 20%. I believe that this accurately reflects the value in the exhibit idea.

3.4. Implementation

We began prototyping with a cardboard prototype and some 3D printed elements designed in SolidWorks. We very quickly sourced the fan from NU Wireless club and I was able to test the modular wind turbine build process. We settled on a central turbine hub with eight slots for various interchangeable blades. This hub could then be mounted as a HAWT or VAWT inside the wind tunnel. The modular blade system underwent several major design overhauls during the course of the project. We switched from mounting the hub directly on the motor to mounting it on a square peg. I redesigned the peg system for the actual blades multiple times in order to correctly dimension and shape the peg. In the end, I settled on a rectangle and round peg system which could orient a turbine blade in just two orientations. This kept turbine designs relatively simple as the blades couldn’t be oriented at any angle, just a set two.

Fig. 1.05 “Simple VAWT Example”

Our cardboard prototype quickly confirmed that our idea of measuring power output with a DC motor would work. It also helped us better understand the dimensions and physical components needed for the exhibit to function.

For the final construction, we laser cut wooden panels and bolted them together to make the exterior of the box. We originally wanted to screw together the wooden sides of the box using internal wooden supports but realized that our panels were too thin, causing the wood to split. I ended up getting metal brackets to bolt the box together from a local hardware store. The clear front panel is laser cut acrylic. The outside of the box was coated in a vinyl wrap along with 3D printed lego studs on the top of the exhibit. A wall-power AC fan was bolted into the box and is controlled from Arduino off a relay. A servo motor is mounted to the door hinge with a 3D printed lever to open and close the main door. A laser cut button mount is placed outside of the exhibit. The “ceiling” of the exhibit is lined with addressable RGB lights which flash a rainbow pattern to attract users during the expo.

The exhibit is run alongside a Unity user interface which displays instructions on how to use the exhibit and how to construct each turbine.

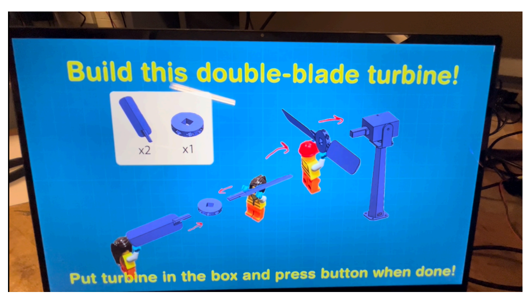


Fig. 1.06 “Unity Building Instructions”

3.5. Evaluation

We evaluated the strength of our final project almost entirely through qualitative feedback and watching users interact with the exhibit. Data was taken throughout the design process in our design notebook as users interacted with our prototype. In our final design at the expo, we took video and notes of how the young students interacted with the exhibit.

From the video, we are able to gather some quantitative data on how long each user interacted with the exhibit, and how long each user took to complete each step.

3.6. Individual Contributions

I contributed to most aspects of this project. I helped with the box assembly. I designed and printed all 3D printed items, and operated the laser cutter for all laser cut components. I contributed to the overall design of the project and used Microsoft Paint and hand sketches to communicate designs. I designed and helped build the electronics systems and assembled JST connectors to make the exhibit disassemblable.

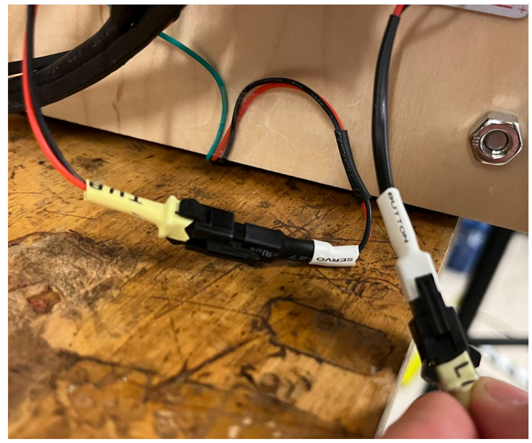


Fig. 1.07 “JST Connectors for Servo and Button”

I did all of the programming for the project including the logic for the Arduino, the driver for the lights, and the Unity programming. I also put a lot of work into redoing the aesthetics of the Unity portion of the design and programming in animations and particle effects.

RORY O'NEILL

1 INTRODUCTION

The most prevalent global issue of the 21st century is global warming and where to get our energy sources from. In the past, all of this energy has just come from fossil fuels. This depletion and burning of fossil fuels has done irreversible damage to Earth. People believe creating electric cars and electric powered engines solve this issue. It does not, it is yet a mere start to the issue at hand. The strive for cleaner energy has been a pressing issue and there are ways in which people can produce clean renewable energy. One example of renewable energy sources is wind turbines. Harnessing the power of wind to create energy is sustainable and a powerful energy source.

2.1 PROBLEM STATEMENT

The problem is that many young students aren't familiar with different wind turbine designs past the classic three-blade turbine. They also aren't engaged with the topic of renewable energy generation. This is important because this new generation will need to focus on the problem of sustainability in their future work. Currently, there are exhibits surrounding wind turbines but they aren't hands-on or engaging enough to capture the attention of elementary-age students. The users need a design that is immediately engaging and focused on creativity while teaching them about the topic at hand. Our solution will be an exhibit that inspires open-ended creativity but also needs to emphasize teaching about different turbine designs. This will include hands-on experimentation and will actively engage young students by giving them freedom and having faith in their competence. Our constraints include a $100 budget and the portability of our exhibit.

The emphasis on teaching was extremely important throughout the design of our exhibit. To do this we made sure to have slides up on the screen that teaches kids about different turbine designs and really pushes a hands-on learning experience.

We are able to keep the costs low for our exhibit because we were able to get materials at a low cost from EXP and sourcing most of the electronics. The 3D prints were all free as we were able to get free filament from the wireless club which also saved a lot of money.

2.2 Stakeholders

The client for the final design project is the Boston Museum of Science where the designed exhibit will be displayed for young students. The museum's main goal is to have an easy way to teach users about sustainability and engineering. A second client is Northeastern’s College of Engineering as our exhibit will be displayed at the first year engineering expo. The target audience of our exhibit is young students who will be playing our exhibits and we will be able to see what we can improve on and what might not work well. These students are around the age of 10 years old so this went into account when designing our exhibit.

2.3 Pertinent Topics In Engineering

Turbine Design

The main objective of the exhibit is to have different wind turbines designed so the young children could stay engaged.

These designs required background research to see what blades produce the most power and introduce us to different designs. The ones we decided on include multiple horizontal turbines, a 1 blade turbine, 2 blade, 4 blade, and a Savonius vertical turbine. These different turbines all have different designs and the main goal of the exhibit is to just see which might be more effective at producing energy versus what might be not as great. This keeps the exhibit simple for the young children.

2.4 Scope

This report will focus heavily on the physical design and construction of the museum exhibit. My role in the exhibit build was to to focus mostly on woodwork, box assembly, soldering, wiring, Solidworks designs, and laser cutting. In this report I will be discussing all of these processes through our milestones.

3 Background

3.1 Research

During milestone 1, each member of our team did research on the topic of wind turbines. Wind turbines have been around since 1887 and it produced electricity. Since then many different turbine blade designs have been designed in order to maximize turbine speed and capture the wind. The most common type of wind turbine is a 3 blade turbine. This turbine is usually located in large fields so it can capture the most wind. It is the most common because it has the best combination of high rotational speed and has minimum stress due to one blade being horizontal and its other two resistances coming from the other two blades.

Fig. 1.10 “3 Blade Turbine”

We were not able to implement the 3 blade design into our exhibit due to our hub design so the next best was a 4 blade. The 4 blade turbine design is similar to the 3 blade in that it has the same turbine blade design. The next blade we researched was a savonius turbine. This is not really a conventional turbine blade because it only works in certain settings. The savonius is mostly used in urban settings where wind can come from all directions.

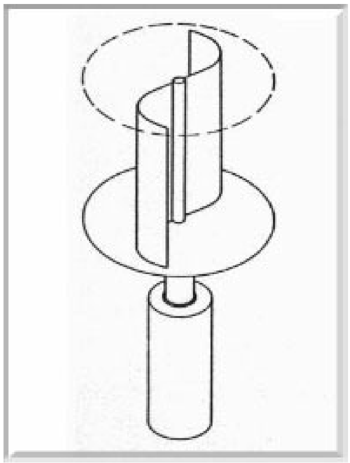


Fig. 1.11 “Savonious Turbine”

The blades are horizontal so it can work in smaller settings. It is not great for harnessing wind power as the blades do not catch most of the wind possible. Another blade design we implemented was the one blade design. We wanted to implement these both into our design as they both work in very different environments.

3.2 Blade designs

There are two different blade designs VAWT (vertical axis wind turbine) and HAWT (horizontal axis wind turbine). HAWTs need to be facing the direction of the wind and it is a fixed position, whereas VAWT is omnidirectional and can be used with wind coming at any direction. This makes VAWTs better in settings like cities where wind gusts can come from any direction. In environments like cities you do not see any HAWTs.

4 METHODOLOGY

Our team began this project by brainstorming possible ideas for a sustainability related topic which was an original idea. We all on our own brainstormed our ideas for the exhibit. The 3 topics we chose were grid energy systems, wind energy, and water power. We ultimately decided on wind energy as we felt it was a topic that not many other groups were doing and we could go to a lot of places with it.

After deciding on wind energy we all individually created drawings of what we thought the exhibit might come out to be. My design consisted of a wind tunnel and having the users design their own wind turbines and see how well they perform. This was able to teach users about different wind turbine designs and make it engaging for the users. After using a Kepner Tregoe Decision Analysis (KTDA) table we ultimately decided on a wind energy design for our exhibit. This KTDA factored in originality, replayability, engagement, and teaching. Ultimately, after meeting with our mentor, TJ, we unanimously decided on my design with the wind turbine. TJ told us that he has never seen something done like this and it has a really great hands-on teaching part of it. We were able to mold this idea into a more concrete design as we added in more elements of teaching into the design.

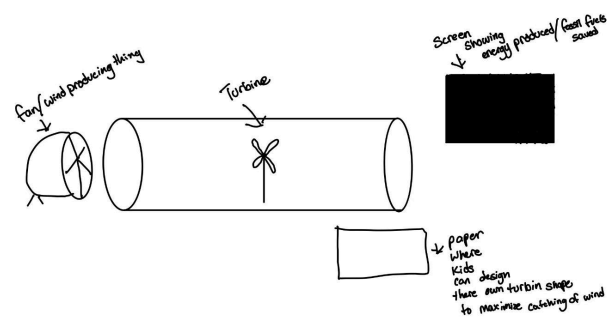


Fig. 1.12. “Milestone 2 Design Sketch”

During milestone 3, we were tasked with making a solidworks drawing of the exhibit and making a cardboard mock up of our exhibit. At this point, we had almost a full idea of how our design would work. We would have a fan that is blowing air to a 3d printed turbine blade. When these turbine blades spin, a motor will be able to act as a generator and see how much power is being produced from the spinning blades. For this milestone, we did not implement any of the electronics but rather just printed out our blades and stand for the blades. Then we wanted to see if it would produce enough power that is readable for the arduino. This mockup was mostly to see how these pieces would fit together and if the design needed to be remodeled. The proof of concept for us was making sure the fan produced enough wind for the turbine blades to spin and produce a current of electricity.

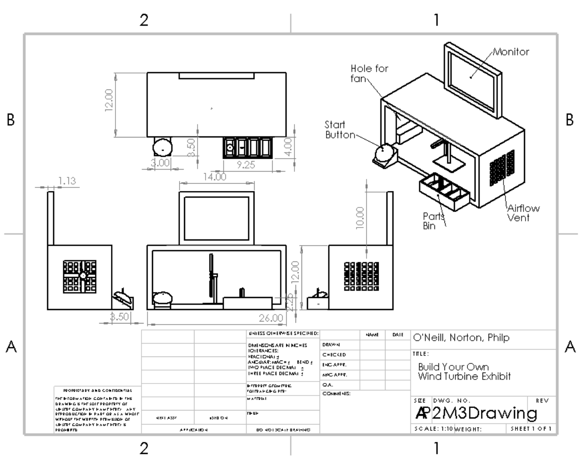


Fig. 1.13. “Milestone 3 Design”

After the town hall meeting for milestone 3 our group decided we wanted to make a few small changes to some of the ideas behind the project. KSG told us that she wanted us to focus more on a learning aspect towards our exhibit rather than purely hands-on elements. Ideas we had for this was implementing a screen in which there are basic facts about the different wind turbine designs.

For milestone 4, we began to construct our project with its final materials. We decided to construct the wind tunnel out of wood and have the front panel made out of acrylic so users could see what was going on in the exhibit without losing wind. We were having trouble putting all of the wood together because wood glue was not strong enough. After some troubleshooting we were able to use metal brackets to secure all of the sides together. We decided to leave out most of the electronics during this milestone because we wanted to make sure the core of our actual build was done in time for the demo. We knew that the actual electronics for this piece was not hard as we already tinkercadded the wire diagram so we knew we were not making a mistake by not focusing on the electronics. We had everything planned out and working nicely but did not have any code or a theme chosen for our design.

After milestone 5, feedback we got from the gallery walk was to choose a theme because it looked bland and to have more facts in the unity. Other than that almost everyone loved our exhibit. During the gallery walk our actual interface did not have any theme to it and was very basic. We focused very heavily in the next weeks on getting a theme and this was mainly my goal. We talked to TJ during the gallery walk and he suggested a lego theme. This theme works perfectly and I then set out on making this theme perfect. We started by building legos and making our actual exhibit a lego brick. I did all of the wiring for our exhibit, I learned how to solder and soldered all of the wires onto a solderable breadboard. We decided to solder because we did not want any of our wires coming off and we did not have many wires in the first place.

After all of this we dedicated our last week to working out kinks in the code and making the unity ready for gameplay. This was a harder step then expected because we kept having trouble with our start button and the unity code and aesthetic.

4.1 Individual Contributions

My individual contributions have been primarily responsible for the physical construction of the exhibit. I constructed the main wind tunnel, the button encasing, design for the trifold, wiring, and more. Along with all of that I did the laser cutting and CAD for all of these objects. Additionally I came up with the idea for the project itself and aided my group members in

miscellaneous work.

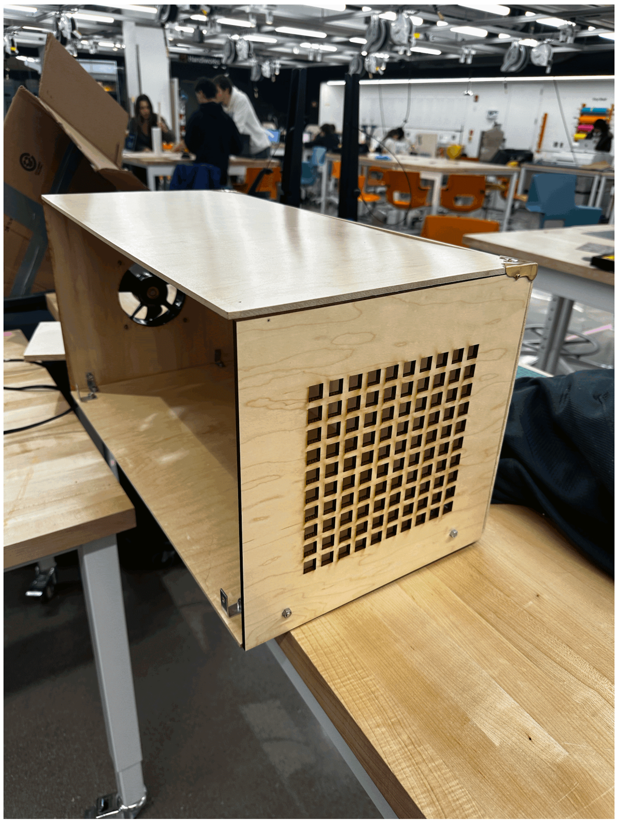


Fig. 1.14. “Box construction”

AUSTIN PHILP

1 INTRODUCTION

As global warming becomes more prevalent in today's society the question becoming more and more prevalent in everyone's mind is - how do we stop it? The classic answers tend to be extremes with people crying out: “eliminate fossil fuels!” Or “Only have electric cars!” However, what a lot of people don't realize is that extremes cause even more problems. If you remove all the gasoline run cars and only have electricity, suddenly people are unable to travel as far, businesses have to pay more for car charging stations, severely increasing their electricity bill every month, which in turn comes out of the employee paychecks. And what would most likely power those stations? Fossil fuels. Overall there is truly nothing we can do in the short term to fix the problem of global warming. However, in the long term the best thing we can do is inform those who will be the engineers of the future. That is what we aimed to accomplish through our exhibit - to teach the youth about one specific form of sustainable energy: wind turbines.

1.1 PROBLEM STATEMENT

The problem we found is that many children are not well educated in the different types of windmill blades and the benefits of wind energy and the energy that can be made with them. Currently there are many exhibits across the US that discuss wind turbines but very few of them are hands on and encourage a creative approach. Our solution is to focus on creative input from the user to create a unique learning experience of their own. To do this we had to keep within the constraints of a $100 budget and keep the exhibit portable.

The biggest emphasis we had was on getting our message across to the kids. So even though they are being creative and are able to customize how they learn we want the lesson to still be there. To do this we created a choose your own adventure style slide show that taught the necessary information while still giving the kids freedom to choose how they wanted to learn.

Keeping within our constraint of a $100 was simple as we were able to source a lot of our materials from ourselves. Any materials we could not get from ourselves was sourced from exp for a relatively inexpensive price.

1.2 Stakeholders

The clients for the final project were the Boston Museum of Science and Northeastern University College of Engineering. At the museum the exhibit will be displayed for all of the students to utilize. The museum's main goal is to teach users about sustainability. For Northeastern the exhibit will be displayed at the engineering expo. Our target audience is young children between the age of 10 and 12 and this was taken into account when we were designing our project.

1.3 Pertinent topics in engineering

A major goal of ours was to have multiple different types of wind turbine blades. This would allow for there to be many different options to help keep the kids engaged.

Each design required research prior to building to discover which blade types would be the most effective at producing energy and which would be the most educational.The blades that were decided on were single blade, double blade, 4 blade, and Savonius vertical blades. As each of these blades is very different the main goal of the exhibit was to allow the kids to explore which is more efficient when providing energy.

1.4 Scope

This report will focus mainly on creating the user interface as that was my main contribution to the project. My role in the exhibit build was helping to build the wind tunnel and building the boxes that held the individual parts, creating and designing the user interface and writing the base code for the game.

2 Background

Research

Single-Blade Turbines: Single-blade turbines have been studied for their potential advantages in reducing manufacturing costs and minimizing structural loads. Research has shown that single-blade designs can achieve comparable efficiency to multi-blade turbines while requiring fewer materials and lower maintenance. However, challenges remain in balancing the rotor and mitigating vibrations.

Double-Blade Turbines: Double-blade turbines have been explored for their improved aerodynamic performance compared to single-blade designs. Studies have shown that double-blade configurations can enhance energy capture efficiency by reducing drag and increasing lift. Research also focuses on optimizing the blade geometry and spacing to maximize power output and minimize noise.

Four-Blade Turbines: Research on four-blade turbines often compares their performance with three-blade counterparts, which are more common in commercial wind farms. Studies suggest that four-blade configurations can offer advantages in certain wind conditions, such as lower wind speeds, by providing a smoother operation and reducing the risk of fatigue loads. However, the increased complexity of four-blade designs may impact manufacturing costs and maintenance requirements.

Savonius Turbines: Savonius turbines are characterized by their vertical-axis configuration and unique curved blade design. Research on Savonius turbines has focused on improving their efficiency and addressing limitations such as low starting torque and cyclic power output. Studies have explored modifications to blade shape, rotor configuration, and placement to optimize performance, particularly in urban or low-wind-speed environments where traditional horizontal-axis turbines may be less effective

3 Methodology

In the initial phase of the engineering design cycle, comprehensive steps were undertaken to fully understand and define the problem. This involved a thorough analysis of the project requirements, client expectations, and any constraints imposed by the project scope. Utilizing the insights gained from Milestone 1, extensive research was conducted to delve into the intricacies of the problem and associated topics. This included literature reviews, interviews with stakeholders, and examination of relevant case studies. The objective was to gain a holistic understanding of the problem space and identify key challenges and opportunities for innovation.

Following a robust problem definition phase, the focus shifted towards generating a wide range of possible solutions. Drawing upon brainstorming sessions and collaborative discussions, various ideation techniques were employed to explore diverse design concepts. Each team member contributed unique perspectives and ideas, which were synthesized to expand the solution space. Examples of solution generation methods included sketching, concept mapping, and rapid prototyping. Through iterative refinement and feedback loops, representative samples of the explored solution space were developed, aiming to address the identified problem from multiple angles.

In the decision-making process, clear criteria were established to evaluate and select the most suitable solution. Criteria were based on project goals, client requirements, technical feasibility, and economic viability. Utilizing insights from Milestone 3, a systematic approach was followed to rank and prioritize potential solutions. This involved creating rank order charts and utilizing decision-making tools such as the Kepner-Tregoe Decision Analysis (KTDA) method. Objective ratings were assigned to each solution based on predefined metrics, facilitating a transparent and reasoned selection process.

The implementation phase involved translating the selected solution into a full prototype in a rigorous and professional manner. Referencing Milestones 4, 5, & 6, the development process followed established best practices and standards. While detailed step-by-step procedures were not provided in this section, phases of prototype development were outlined to showcase the rigor of the process. External instructions or standards were referenced where applicable, ensuring adherence to industry norms and quality standards. Any detailed explanations deemed necessary for process recreation were provided in appendices to maintain clarity and focus.

Covering all steps, including testing and analysis, as outlined in Milestones 4, 5, & 6, the evaluation phase was integral to validating the prototype's adherence to design requirements. We meticulously collected data through testing procedures outlined in the project plan. Analysis methods were applied to interpret findings and identify areas for improvement. Major design decisions influenced by evaluation findings were mentioned to provide context. Detailed results were not discussed, as they are presented in a separate section. However, any significant findings impacting the design process were highlighted to ensure transparency.

Individual Contributions

My individual contributions included helping out with the construction of the wind tunnel that was the main part of our exhibit. However, my main contributions came from the creation of the user interface. I designed the slides via photoshop and then uploaded them onto the interface via unity. I then built the base code in which our final code was built off of. The base code allowed for us to run the program via a computer keyboard prior to the addition of the arduino.

TEAM 4

5 FINAL DESIGN

5.1 EXHIBIT OVERVIEW

Our final exhibit consists of a 24”x12”x12” wooden box with an acrylic front panel, a large green button with a stand, and three wooden bins with modular turbine pieces inside. A monitor sits on top of the box displaying important information about playing our game and the instructions in each step of gameplay. The acrylic panel has a door which allows access to the inside of the wind tunnel. The user will construct a small wind turbine blade layout using a modular peg system and place their design into the wind tunnel. A sequence will be initiated, blowing wind through the tunnel in order to spin their small wind turbine. A readout of their power output will be shown on the monitor.

Fig. 1.20. “Full expo set up”

5.2 USER EXPERIENCE

Our project is themed after LEGO, in the hopes that the user is familiar with the toy and is therefore less intimidated by our exhibit. We also hope that the theming attracts users and keeps them engaged.

The Unity interface is designed to allow the user to choose how they would like to learn about wind turbines. This process is done by allowing the user to choose what type of wind turbine blade they would like to learn about. The user is able to run the interface through a button controller connected to the Arduino microcontroller. Once the user learns how the blades work they are then pushed to create said blade. Via the interface and the microcontroller the user is informed how much power the blade is able to generate. After the user builds the blade they have chosen they are then prompted to use the blades supplied to them to build their own turbine.

The blades are made of a plastic filament, and are built in a way that will reduce them breaking if put under large amounts of stress. The hubs that hold the blades are made out of the same plastic filament.

5.3 Functional Components

The design that attaches the hub that holds the blades to the stand for the wind turbine was done by having a cut out square in the middle. This square was just big enough to fit snugly into a rectangular piece that was attached to our motor (fig. 1.22). This was the primary design for the exhibit as it was the way kids attached their designed wind turbines to the motor that read the energy output.

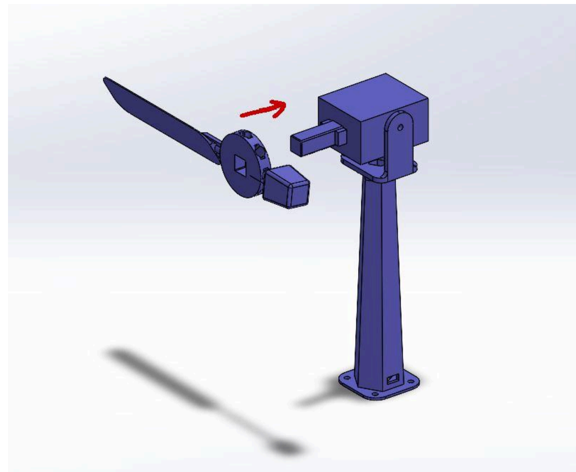


Fig. 1.22. "1 blade turbine assembly"

Another key functional component of the exhibit was the mechanism in which the motor can switch to vertical for VAWTs. This mechanism was done by 3D printing hinges in the motor encasing and making it stay by having a mechanism that clicks it into place. The motor being horizontal (fig. 1.23).

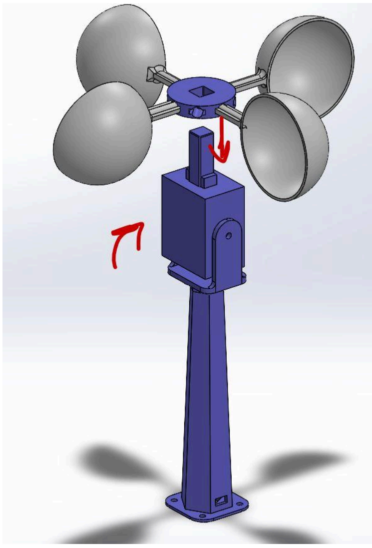


Fig. 1.23. “Cup assembly”

One last mechanism was opening and closing the door. We used a servo that was attached to the door that was integrated into the code that was able to open and close the door so that the users did not open it during the experiment.

5.4 ELECTRONICS/SOFTWARE

The heart of the electronics included in the project are run off of an Arduino microcontroller. The main components connected to the Arduino are a relay, lighting control, the button input, door servo, and DC motor passing through a full bridge rectifier.

The Arduino runs the logic of the program. It uses a state machine with each slide of the program mapped to a different state. Each state has different inputs which can be made with the button. For example, the opening screen simply requires a button push to switch to the next screen. The “choose a design” screen requires a two-second hold to switch to the next screen. A single push switches which turbine design is selected.

The relay in our exhibit is used to drive our main fan which runs off 120 VAC wall power. Since this power cannot be sent through the Arduino microcontroller directly, a relay is used by the Arduino to switch the high powered fan on and off during the “run” stage of our exhibit.

The lighting in our exhibit consists of three stages of individually-addressable high-density LED strips run along the “ceiling” of our wind tunnel. These LED strips are driven by a 5V power, ground, and data-in pin. The data-in pin is the only pin connected to the Arduino. It automatically sets up addresses and sends data to the integrated circuit (IC) in each LED along the strip through a pulse-width-modulation (PWM) signal. The LEDs are driven off the “FastLED” Arduino library by Daniel Garcia. The power pins of the LEDs are driven through a separate 5VDC power supply, as they draw 800mA, much higher current than the Arduino 100mA max current output.

The LEDs run through a series of patterns along each stage of a playthrough. During the opening stage, the LEDs will flash through an offset “spectrum” mode (aka rainbow colors) to attract users. During the “build” stage, the LEDs will be full white to allow the user to better see what they are doing. During the “run” stage the LEDs will scroll white lines to show that wind is flowing through the tunnel. During other stages, the lights will be a dim red to not distract from the monitor.

The servo motor is used to control the door of the exhibit. This servo is also powered off a separate 5VDC power supply as it draws a couple hundred milliamps: more than the Arduino can supply. The Arduino controls the angle of the servo through the data pin with PWM signals. It controls the exact angle by sending PWM signals with a longer and shorter duty cycle in a certain frequency. The door of the exhibit swings open during the “build” phase and closed during the “run” phase of the playthrough.

The speed of the spinning turbine is detected through the voltage output of a small DC motor connected directly to the rotor. Because the rotor can run clockwise or counter-clockwise, the voltage from the DC motor can run in either direction. The Arduino’s analog input pins however, can only detect voltage in the positive direction. To remedy this, a simple full-bridge rectifier circuit is attached between the DC motor's output and the analog in pins, correcting the output voltage to positive no matter which direction the DC motor's electricity is flowing.

The Arduino outputs a seven digit data stream every 100 milliseconds from its micro USB port into the computer running the Unity program. In this case, we used a laptop connected to a monitor on top of the exhibit. This laptop runs the .exe Unity game. The Unity game doesn't send anything back to the Arduino, in this way, the Unity program is read-only.

The seven digit data stream sent first contains two verifying digits, to ensure the steam is being sent correctly. It then contains a digit for which slide of the presentation to be on, the welcome slide, choose a design slide, build designs slide, etc. After that, a digit for which wind turbine design is being built, which maps to single-blade, double-blade, etc is sent. Finally, the three last digits are used for the analog input voltage of the motor spinning, which can be mapped to a slider in Unity to show a live feed of the generator output.

6 Results

The exhibit runs properly with no major bugs or game-breaking design issues. The project fits snugly in our allotted carrying bag. The total project cost of the project comes out to ~$69.00.

At the expo, our project was frequently surrounded by at least four elementary students. Every student fully finished the first half of an exhibit playthrough and most finished the full exhibit playthrough, including the build your own turbine section. Turbines designed by the students usually had six blades or more and almost always had combinations of at least two different types of blades.

Kids tended to spend a fairly short period of time reading the educational turbine slides, with the mean time spent being around 10 seconds.

Almost all students tried to manually close or open the door labeled “Don’t open by hand”. Most appeared excited during the playthrough and some talked with their friends about the power numbers they were generating as they played

LEO NORTON

7 DISCUSSION

I believe that our final design was overall successful. It fulfills almost all requirements set in our constraints section, as it was within budget, size requirements, safe, and taught sustainability topics.

The UI attracts users through the theming and the animations. The lighting used in the exhibit also played a large role in attracting students to the project.

Users were largely kept engaged with the project and found designing their own wind turbines to be a creatively stimulating and satisfying task. Some kids also were very engaged with the competitive aspects of the exhibit, trying to one-up their friends one turbine construction.

There were a few weaknesses to our exhibit design. The door of the exhibit was not intuitive, as most wanted to open and close it by hand. The children had a good amount of trouble with physically assembling the turbines. The peg and hole system was a little tight and many kids had to ask for help in assembling a turbine.

Some users also got inpatient in the testing phase of the exhibit as once the turbine gets up to speed, not much changes for a good 10 seconds of turbine run time. Occasionally, a user would decide to skip the second half of the exhibit. Usually it seemed as though they didn't want to wait for this timer again.

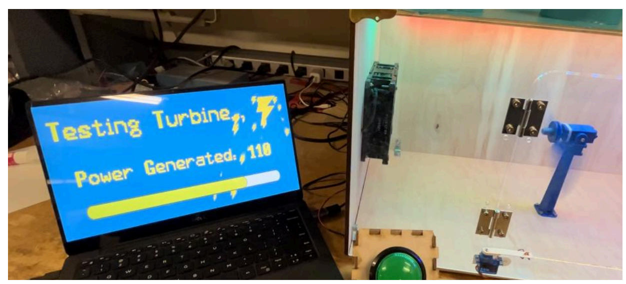


Fig. 1.30 "Testing Turbine Screen"

7.1 EASILY MEASURED GOALS

Our exhibit cost us $69 to build, including wood, brackets, components, etc. This is well within our $100 budget.

Our project measures 24” x 12” x 12”, allowing it to fit easily within our allotted project box.

Finally, our project was saved as we put multiple safety features which kept the young children from being able to touch any spinning rotors while moving. No one was injured in any way by our exhibit.

Our exhibit ran correctly for the entire expo without bugs or game breaking design flaws.

7.2 Hard To Measure Goals

We definitely succeeded in our goal to attract many users to the project. I believe the rainbow lighting and LEGO themed Unity page attracted a lot of users to our exhibit during the expo. Users were also unafraid to interact with the project as they are able to understand what the project was about as soon as they saw the theming.

Fig. 1.31 “Start Screen”

Users were also very entertained by the system, and were engaged by the hands-on elements. Multiple children talked to their friends about the exhibit while playing it and watched their friends playthroughs.

One of our main weaknesses was in the educational aspect of the exhibit. Many users also skipped past the “learning slides” during their playthroughs. It was common for kids to almost completely ignore the informational wind turbine slides and skip past them by hitting the button.

I feel we were largely successful in our goals however, as the users became more excited about sustainability topics and were enthusiastic about the process of designing and building rotors. In this way, I feel we educate students purely through the hands-on design process of designing and building their own wind turbine.

8 Conclusion

Our given problem was to develop a museum exhibit for elementary-aged children which taught about sustainability topics in a fun and engaging way. To address this problem, we developed a modular wind tunnel based game in which the user would build and test a wind turbine, learning about rotor design in a hands-on way.

I believe our final design did an excellent job at fulfilling the requirements of the project. It was able to engage young students very effectively. It taught largely through hands-on experience and engaged their critical thinking skills and tested their knowledge in allowing them to build their own wind turbine.

Our design process methodology helped us decide our best idea to address the given problem, and iterate on a design process until we had an optimized physical design. Using brainstorming techniques and a KTDA chart helped us greatly in the generation of concepts for our project and objectively determining the best of our ideas.

Hand sketches and 2D and 3D computer aided design allowed us to quickly iterate on the overall design of the exhibit. We were able to see major issues and fix them before encountering them during building. The modular turbine system was made possible through large amounts of 3D printing and design iteration of the assembly system.

The user is guided through the experience effectively using an engaging graphical user interface. This user interface was designed several times in order to be informative as well as engaging for kids. Few users were confused by the instructions given by the user interface.

In our testing phase, our exhibit was popular with the young students. We had some trouble with students struggling to assemble the system, but most seemed to really enjoy the game. Most students also didn’t spend much time on the text information portion of the exhibit and instead opted to skip forward to the building sections. I feel we still educated the young students however, as they continually learned from how well their and their friends rotors performed.

I feel the project engaged them in the engineering design process overall. Potential impacts of our exhibit include inspiring the next generation of engineers and getting these young students interested in sustainability topics such as wind turbines. I hope that students who engaged with our project will be more inclined to get involved with engineering and wind energy in the future.

9 RECOMMENDATIONS

9.1 TUNNEL AIRFLOW

There are a few areas in which the design of the product could be improved. At the beginning of the project, I would've liked to test the wind tunnel airflow a bit more. There was some turbulence created in the back of the enclosure which reduced the spin on some of the wind turbine designs. I would overall like to make it easier to create a functioning wind turbine design. The entire wind tunnel could be smaller as well to increase the pressure of the airflow through the center.

9.2 ASSEMBLY SYSTEM

The design of the assembly system could be improved, as it was difficult for some users to assemble their rotor. I would bevel each peg more to improve this. I would also create a nicer, tension based holding system for the propellers instead of being purely based on a snug fit with the hole.

9.3 EXHIBIT DOOR

The main door of the exhibit could be improved, as users were often tried to open and close it by hand. This automatic door could be replaced by a sliding door with a linear actuator to remove the risk of breakage due to misuse.

9.4 LEARNING SLIDES

The “learning slides” could be greatly improved to deliver information in a more digestible manner. The somewhat large block of text doesn’t engage the reader and they skip it. I feel a good way to fix this would be to make the learning slides play on a timer and give information about the wind turbine while the turbine is spinning. That way the user could read the slides and look at their turbine spinning if they get bored. Information would also be delivered at a slower rate, spread out over multiple slides to improve digestibility.

9.5 Addressable LED Effects

Our original idea with dynamic, individually addressable LED strips inside the box would have helped communicate the steps of the exhibit better. The project was originally set to have dim lights when the user should look at the screen, have white lights when the user needs to interact with the box, and have moving wind lights when the fan is running. I didn't fully implement this idea because of time constraints.

9.6 Turbine Variety

More turbine blades could have been created to show off some other types of exotic wind turbines. Blades shaped more like real life blades could have been made to demonstrate how real life turbines work. This could improve the amount that was learned at our exhibit.

9.7 Power Generated Resolution

Another improvement I would like to make would be to increase the resolution of the power generated meter. The resolution of the current system is about 14 steps corresponding with the power level being generated by the turbine. I feel that showing a more detailed meter with more steps would greatly increase the engagement with the "testing phase" of the playthrough. This electronics problem could be done in multiple ways. Currently, the voltage generated in the DC motor is too small to map to much of the 1024 unit resolution of the Arduino, only taking up around 0.02% of the available input range. This problem could be solved with an operational amplifier circuit which would amplify the small voltage created to fill this range. The entire system could also be replaced by a component such as a magnetic encoder, which would reduce friction in the turbine and raise the resolution of the system. If this replacement was made, some novelty might be lost as the system is no longer actually generating electricity like a real wind turbine.

10 Lessons Learned

During the course of this project, I learned multiple lessons about myself, my limits, and working on managing and working with a team. I've had to work much harder than I have in the past to complete this project while keeping up with the other commitments and classes in my life. Managing a team, and playing off each member's strengths was a challenge that I believe this team managed.

10.1 Contributions

I contributed significantly to various aspects of this project. I worked on the design and assembly of the overall wind tunnel box, handled the design and production of all 3D printed components, and operated the laser cutter for all relevant parts. I designed and played a large part in the construction of the electronic systems in the project. I wrote all the code for the project and also did graphic design on the slides.

Finally, I feel I helped guide my teammates on aspects of the project that they were struggling with, or weren't familiar with. I delegated tasks to them a good amount.

10.2 Resources

Our group spent a total of $69 on the project, meaning we were well within our budget. I personally purchased brackets to build our overall box, and sourced electronic components for it. I acquired the electronic components that weren't in the Sparkfun kit such as the wall power fan, the relay, the solderable breadboard, the addressable LED strips, etc.

I devoted large portions of time to the project, especially towards the end, as we approached the expo date. The programming was a large time sink as I wasn't extremely well versed in writing a project like this in Arduino. I spent a lot of time debugging code in the downtime waiting for the 3D printer.

This experience has greatly improved my time management. I feel I learned how to create a minimum viable product quickly. I prioritize my work in order to finish the most important components of the project quickly, working on the less important features last, such as the addressable LEDs or the Unity animations. I will use these lessons to work more efficiently in the future.

10.3 Reflections on Learning

From this project, I greatly improved my SolidWorks skills. Creating the modular wind turbine system from scratch was a challenge unlike projects that I had done before. Using SolidWorks to design more advanced parts of the system, such as locking joints, print-in-place hinges, and latches was somewhat challenging. I feel I learned a lot about modeling and 3D printing from these tasks.

I also learned a lot from writing the Arduino code used in the program. I learned how to make a state machine in Arduino with an enum in order to better organize my game's run cycle. I also learned how to integrate Arduino with Unity to add an advanced UI to an Arduino project.

I am proud of these new skills and feel that they will all help me in my career as an electrical engineer.

10.4 Reflections on Working in a Team

This project improved my delegation skills in teamwork. It also improved my skills with cooperation and keeping members happy and working on things that they are interested in. In a group of only three, with one member dropping, it was difficult to stay completely on top of the workload. We were challenged by the amount of work each of us would have to do in order to stay on top of milestones and get our final, somewhat ambitious, project done. I still need to work on telling others what they should be working on at any given point as a lot of the work fell on me towards the end and I didn't put in the time to train other members to get them involved.

I would describe my leadership style as very laissez faire. I largely do work that I don't want to get involved in the tasks that my teammates are doing. I am somewhat poor at delegating tasks to others and feel that because I can do the tasks quickly, others shouldn't worry about learning a new skill to do a task that I can do fast. In this way, I sometimes take on more than I can chew as a leader.

I feel that I can be managed easily, as I am fairly laid back and willing to work on any aspects of the project I am designated. As a team, we worked to overcome adversity by making sure everyone was on the same page about the work being done. Communication was important and we taught each other skills that were useful for the project.

I feel that my biggest asset to the team was the time I put into the project and my knowledge of programming and electronics. I feel that I contributed a lot of the autonomous aspects of the exhibit.

If I were to start over from the beginning, I would do many of the items I outlined in the "Recommendations" section. Most importantly, I would resize the wind tunnel to be smaller. Overall, I would've liked to add more of a artistic flare to this project. I would've liked the project to be a bit smaller and more dense with artistic touches rather than its large size and sparse. I also would’ve liked to add in some more technologically advanced components into the project. A small OLED screen, or magnetic encoder would be an example of this.

Rory O'Neill

11 Discussion

Our exhibit was an overall success. The children loved our exhibit and were really engaged in it. Our problem statement laid out objectives for us that we feel we met by the end of it. One of our main goals was to educate children on wind turbines. We feel we did because we saw the children understanding that the 4 blade turbine worked the best and they were reading our slides. We were able to keep our budget that was set at $100. One of our weaknesses that we noticed was that the children were having difficulty putting the blades into the hub. This was a small factor as the children were able to figure it out after a while.

11.1 Easily measured goals and requirements

Our exhibit was 24in x 12in x 12in which was fairly large yet fit within the size requirements set by Prof. KSG. This size constraint was a blue moving bag which fit our design snugly and was not oversize at all. We were able to store the majority of our miscellaneous items inside of the wind tunnel as it was the majority empty space which saved us a lot of room. We did not put our monitor in the bag but this was just to make sure the monitor was safe and did not get damaged.

11.2 Harder to measure goals and requirements

A constraint that is harder to analyze is whether or not this taught the children anything about wind turbines. This was one of our goals in our problem statement. Our main opportunity for teaching during the exhibit was a slide after the kids designed one of the four options for wind turbine design. I found that while watching the students play the game that they often skipped over that slide. I still believe that the students learned something as some kids when designing their own turbine they found that some designs just did not work at all and their friends took note and made better designs. Another goal of ours was to make it fun for the children.

Fig. 1.32 “Fellow college student having fun with exhibit”

We definitely had children attracted to our exhibit because they were telling their friends and more and more students were coming up to us asking to play. We also wanted to make sure our game played smoothly and well. Everything about the game was smooth and straight forward. We used one button for the entire game so the kids did not have added complications.

12 Conclusion

Our given problem was to design a museum exhibit for elementary school children that taught them about sustainability. One of the main goals given to us was that this exhibit had to be fun and engaging for the students and they had to take something away from it. We were able to address this problem by designing a wind turbine game which had students build their own wind turbine designs and learn about different blade designs. This was done in a hands-on way.

In my opinion, our exhibit did an excellent job at fulfilling the given problem. The elementary school students were able to learn about sustainable wind energy while competing against their friends and having fun doing so. It was able to teach the kids in a hands-on engaging way as well as testing their critical thinking skills when they were tasked to design their own wind turbine and see how well it performs.

Our design process aided us in big and small problems throughout the entire process. To start we were able to decide on which idea for the given problem was best using empathy maps and KTDA tables. This aided us in thinking about the stakeholders and users and ultimately led us to deciding on what we thought was the best idea for the given problem. These charts were able to provide us with an unique idea and made it easy for us to set forth on our future milestones.

Our mock-ups, sketches, and 2D computer models aided us in major and minor design changes throughout the project. To start off, our mock-up made us realize how big our design was and made us realize we needed to downsize, from this we were able to re-configure our solidworks model before we were starting on our final design. All of our turbines were made possible due to 3D printing. This was great because we constantly made changes to our prints which gave us optimal results during our process. There were constant blade redesigns and different hub mechanisms in order for us to get the best results.

As a result of our empathy map and really taking users into account, we were able to adapt our digital interface to grab the users attention and really engage with them. This was done with multiple redesigns of the interface. We tried different colors, designs, and added flare so that we could grab the attention of the students. This really aided us during the expo because many students were coming up to our exhibit with their friends. I felt we had a constant flow of students at our exhibit with little to no downtime without students and I attribute that to our flare.

During the expo our only trouble was when students could not fit the blades into the actual hub that held all of the blades. This was a minor issue as students were able to figure it out after a bit. Also, we had a screen that taught about the turbine design that the kids were tasked to build but students often skipped past this slide in our Unity. This was our main slide for information and most of the students skipped this, but they most definitely still learned during our exhibit. I examined and noticed that students were learning from their friends' failures from their designs and were able to adapt their design to produce the most energy.

The potential impacts of our design is inspiring younger generations to become engineers. Our design was able to teach younger students about sustainable energy in a fun and engaging way, this might make students want to pursue this as it introduces the topics and learning skills used in this field.

13 Recommendations

13.1 Blade hub design

While testing our exhibit with the students, our main problem was the hub design as students could not easily put the blades into our hub. This led to some students getting frustrated and we had to come in and help them out. After the expo, I had thoughts of some redesigns. My first recommendation was to just use a velcro system. Although it might look a bit unprofessional, when thinking about the users we are dealing with, elementary-aged students, it is quite easy for them and would be self explanatory. My thought was to cover the front face of the hub with velcro and then have each blade have velcro on the end of this. This makes it so it does not limit designs that the users want to make and have endless possibilities. This is great because one of our other problems was that our hub design had 8 sections in which the blades could be put in, this limited users as it was not possible for them to make 3 blade or 5 blade designs.

13.2 Button and screen selection

One very small issue was that one button was used for screen selection. We implemented code to make this button just be pressed to scroll through the selections and held down to select an option. The only issue with this was that when selecting an option the user had to hold down the button for what felt to be a long time but in the code it was only 2 seconds long. This could have been fixed during testing stages. We should have ran through the game a couple more times and realized that this might be an issue for young students who might have a short attention span.

13.3 Acrylic piece

The front of our exhibit was an acrylic piece with a door on it so that users could see what was going on inside of the exhibit when the turbine blades were moving. This acrylic piece was broken during assembly. The piece was bolted together using metal brackets and we tightened the bolts too much which put tension on the acrylic. This caused the acrylic to break in corners leaving it to look a bit unprofessional. If there were more time we would have replaced this piece and maybe figured out a way to put this piece on without using bolts. One idea for a redesign is to laser cut puzzle piece edges on the design so that it would just be held together with glue. This would leave the exhibit looking far more professional.

13.4 Information slides

A big problem during our exhibit was students skipping past the information slides. If there were more time I would like to implement questions that may be asked that the students have to answer in order to move on. This would make it so students are somewhat forced to read the slides before moving on to the more fun activities.

14 Lessons Learned

During this course was the first time I was able to really work in a group scenario and rely on other people. Our team contract was really reliant on showing up and carrying your weight during the project. I was very involved in our project and always showed up to meetings. While I was project manager I always made sure to hold my teammates accountable and schedule time which would work for everyone. I was able to schedule 3 meeting times while I was project manager. One meeting time was to get all of our mock-up finished, and the others were for memo work and just to talk about possible changes to our design.

14.1 Contributions

My contributions to the design was mainly focused on the physical aspects of the exhibit. Between milestones 5-7 I was working away at designing and building the encasing for our wind turbine. This included a solidworks model and laser cutting wood which included cad designs. We laser cut a door and holes into the acrylic, a vent on one end of the tunnel, and a hole for the fan on the other end. I did this all in CAD and then uploaded it to the laser cutting in EXP. With Leo's help, I was able to learn how to solder and solder all of the wires and hardware to a breadboard and did most of the wiring. This was a valuable skill to learn as it was able to save my group members loads of time. I also designed and made the trifold for our project. This was done by constantly checking in with our mentor TJ, we made sure to look at the lego website and see what color designs they have and match that to our trifold. Along with that, I applied acrylic to all of the sides of the turbine and implemented our 3D printed lego pieces on the top of our design (Fig 2.1).

Fig 1.33. “Student Playing Exhibit”

I also designed and did the CAD for the button encasing of our design (Fig 3.4). This was a last minute piece and required a quick turn around. Additionally with all of this, I was able to contribute ideas and insight on things that Leo had ideas for and help with some research for our learning slides on Unity.

14.2 Resources

Our group's budget was set in the problem statement and was $100. We only ended up spending $69 which puts us at $31 under budget. This was able to be done due to the amount of sourcing we did. We were able to source the fan from a club Leo is in and had all of our 3D printing free due to that club as well. We were also able to source the monitor, as well as the button, and got our trifold printed out for free. Our main expenses were wood and acrylic.

Personally I bought most of the wood and acrylic, but we always split the cost 3 ways on any purchase we made so that not one person was spending too much.

Overall we spent roughly 200 hours on this project. I spent about 60 hours by myself. This includes all of the meetings, work time, and material gathering for the project.

This project has changed me a lot with respect to resource management. To start off, it has shown that keeping logs of all expenses, hours, and more has really proven to be useful for the project and keeping everything organized. The team contract also really keeps people in check as they have written to promise to abide by guidelines.

14.3 Reflections on learning

This project has taught me a lot about group work and problem solving. Before this project, I have not really had the chance to work in groups and really put minds together. This project has taught me how to bounce ideas off one another and really combine thoughts into one single idea. It has also taught me a lot about organization. I have had to make calendars and organize my time around meetings and work time. Not only that but organizing thoughts and ideas and writing them down into our design notebook and it has proven helpful.

Working in a group was completely new to me. It was hard for me to rely on other people doing their part of the work at first because I have never really experienced that in my time at school. I also found it new to manage people, if someone was not picking up their slack I did not know how to approach it and call them out for it. Being able to work in an environment where if someone was better at something they could handle that while I handled something I was better at was also new to me because I have always just been doing all parts of assignments. For example, because Leo was better at coding I was able to do more of the physical attributes.

I have now learned how to solder because of my teammate teaching me. I am really proud of this because it is a skill I have always wanted to learn and I ended up becoming really good at it. I also learned a lot about different electronics and how they work during this project. It has really opened my eyes to the electrical side of engineering and I find it very interesting. This will help me in my career going forward as I can now say I know how different electronics work and not be completely confused about it.

14.4 Reflections of working in a team

This project has really made me a better team member. At first I was kind of slacking off but soon realized I was a vital member. I was able to feel for other people and take on tasks in order to lighten others' loads. I was also able to really learn how to combine ideas and improve on them and really make a great one idea. This collaboration was a big struggle of mine at first and at the end we were super cohesive.

Over the time that I was working on this project I found myself not prioritizing what was needed to be prioritized. After a reality check, I overcame this by devoting my time to the project and really buying into what needed to be done. We also had a few struggles throughout the project as our team was a 3 person group so each member had to take on more responsibility. This was definitely a hard challenge to overcome but once we got our idea down the minds started to flow and we were able to get things done.

I still need to work on certain attributes for my team work. To start off, I need to be there for my team more often. I found myself prioritizing outside activities when I should be helping out my team. I also feel that I could work on splitting up the work better. A lot of weeks we found that either one of my teammates or I have a bigger workload then the others. Also, communicating more to my team would have been a good skill to improve. I need to improve on saying my ideas out loud instead of going with what other people say.

When I took my project manager role my leadership was very good. I feel that I was able to organize the team and make sure everyone was there and accountable. When I had this responsibility I made sure everyone was on top of their work because I really like to get things done and out of the way.

On the other hand, me being managed by a project leader is quite good. If a manager gives me a task I make sure to get it done so I do not hurt the team and put more work on other people's shoulders. If someone tells me to do something I do not argue back but rather help them out.

As a team we were set off with a disadvantage of not having a fourth group member. To counter this we really had to take on more work individually and prioritize more time for the project. It was a bit hard at times as team members did slack off and it put more work on others in our group.

My biggest asset to the team in my opinion was my ability to do physical design. I worked as a carpenter for a couple of summers so I have been experienced in woodwork. This aided us in our design as we were able to get a bunch of the physical things done early. I also feel that my ideas are very valuable for the team. The original idea for the exhibit was my idea and we worked off of it.

If I were to go back to the beginning of the semester and start over again I would have done a couple of things differently. I feel that we struggled a lot with distribution of work, a solution to this would definitely be that at the beginning of each milestone I set out what each member of the team would do for the week. This would help even the load and keep everyone accountable. I also feel that I wish I did not put things off until the last minute, I found myself often scrambling to get things done at the end of the weeks for milestones.

If there were more time I would have loved to have added more turbine blades. This would make the students have more creativity in their designs and use more blade types.

Austin Philp

1 Discussion

In this section, we critically evaluate the success of our prototype in meeting the requirements outlined in the problem statement. We compare the final design against the original goals, objectives, and constraints, discussing both quantitative and qualitative aspects of the design.

Easily Measured Goals and Requirements

Our prototype effectively met all easily measured goals and requirements, including physical constraints such as size, weight, and power consumption. For example, our wind turbine prototype adhered to size and weight limits specified in the project brief, ensuring compatibility with intended deployment environments. Quantitative testing confirmed that the prototype generated sufficient power output within specified wind conditions, demonstrating its effectiveness in harnessing renewable energy. These easily measured metrics provide clear evidence of the prototype's success in meeting design requirements.

Harder to Measure Goals and Requirements

In addition to easily measured metrics, we also considered harder to measure goals and requirements such as educational value and user engagement. Qualitative feedback from user testing highlighted the prototype's educational benefits, with users expressing increased understanding of renewable energy principles and wind turbine functionality. Moreover, observations during testing indicated high levels of user engagement and enjoyment, suggesting that the prototype successfully fulfilled its role as an educational tool. By triangulating qualitative findings with quantitative data, we provide a comprehensive analysis of the prototype's strengths and weaknesses in meeting these subjective requirements.

Strengths and Weaknesses

Strengths of the prototype include its robust design, efficient power generation, and user-friendly operation. The use of high-quality materials and components ensures durability and reliability in various environmental conditions. However, weaknesses were identified in areas such as instructional clarity and ergonomic design. Users reported difficulties in understanding assembly instructions, indicating the need for clearer instructional materials. Additionally, ergonomic improvements could enhance user comfort and ease of operation, addressing usability concerns raised during testing.

Comparison Against Baselines:

Comparisons were made against existing wind turbine designs and educational resources to contextualize the prototype's performance. Our prototype demonstrated comparable or superior power generation capabilities compared to similar-sized turbines in the market. Moreover, its integration into educational curricula was assessed against established educational resources, with favorable feedback from educators and students indicating its effectiveness as a teaching tool.

Conclusion

In conclusion, our prototype can be considered successful based on its ability to meet design requirements and stakeholder expectations. Through a comprehensive analysis of both quantitative and qualitative data, we have demonstrated the prototype's effectiveness in addressing a wide range of goals and requirements. By leveraging user feedback and benchmarking against existing baselines, we have identified areas for improvement and future development. Overall, the prototype represents a valuable contribution to renewable energy education and highlights the potential for further innovation in this field.

Recommendations

1. Enhanced Instructional Materials

User feedback highlighted difficulties in understanding assembly instructions, indicating the need for clearer instructional materials. Develop comprehensive instructional guides with step-by-step visuals and simplified language to improve user understanding and streamline assembly processes. Utilizing more CAD diagrams, annotated photographs, and instructional videos to supplement written instructions, providing multiple learning modalities for users.

2. Ergonomic Improvements:

Users reported ergonomic concerns, suggesting the need for improvements to enhance user comfort and ease of operation. Redesign components such as handles and control interfaces to optimize ergonomics and user interaction. Conduct ergonomic assessments and user testing to identify areas for improvement and refine design elements for enhanced usability.

3. Integration of Remote Monitoring System

Remote monitoring capabilities would enhance the prototype's functionality and enable real-time performance tracking and diagnostics. Integrate sensors and telemetry systems to enable remote monitoring of key operational parameters such as wind speed, power output, and system health.Develop a user-friendly interface for accessing monitoring data and implementing alerts for system abnormalities, enhancing operational efficiency and maintenance capabilities.

Lessons Learned

Contributions

Between Milestones 5-7, I contributed significantly to the prototype's design refinement and testing processes. Specifically, I led the ergonomic assessment efforts and implemented design modifications based on user feedback. Additionally, I conducted performance testing and data analysis to validate the prototype's functionality and adherence to design requirements. I also was the driving force behind the graphic design elements of the user interface.

Resources

Our group successfully met our budgetary constraints by carefully allocating funds for materials, components, and equipment. Personally, I acquired additional resources such as the LEDs inside of the box and the lego characters needed for the user interface. I devoted approximately 15 hours per week to the project, and did everything in my power to meet project milestones.

Reflections on Learning

Through this project, I learned valuable lessons in project management, technical problem-solving, collaboration, and time management. I expanded my knowledge of renewable energy systems and gained hands-on experience in prototype development and testing. Additionally, I honed my communication and teamwork skills, effectively collaborating with team members to achieve project goals.

Reflections on Working in a Team

This project challenged me to adapt to diverse working styles and effectively communicate ideas within a team setting. I overcame challenges through open dialogue, constructive feedback, and shared decision-making processes. Moving forward, I aim to further develop my leadership skills and foster a collaborative team environment to drive project success.

Recommendations for Future Projects

If I could go back to the beginning of the semester, I would prioritize early user feedback and usability testing to inform iterative design improvements. Additionally, I would allocate more time for comprehensive prototyping and validation to mitigate design risks and ensure robust performance. These adjustments would enhance the overall project outcome and facilitate smoother project execution

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Author Biographies

Leo Z. Norton

was born in Boulder, Colorado in 2005 and graduated from Fairview High School in Boulder in 2023. He is now a freshman in college, studying electrical engineering at Northeastern University in Boston, Massachusetts.

He largely focuses on the development of analog circuits with interests in HF signal processing and wireless power transfer. From 2021-2023 he was a federal employee at the National Institute of Standards and Technology in Boulder, Colorado focusing on quantum entanglement based random number generation and optical to microwave transduction for superconducting quantum computers.

Mr. Norton was the recipient of the NIST CHARIoT Challenge "Most creative method of interaction with AR prototype hand gesture" award in 2020 and has a game on Steam.

Rory J. O'Neill

was born in Worcester, Massachusetts, in 2005. He graduated from Shrewsbury High School in Worcester county in 2023. He is now a first year college student studying civil engineering at Northeastern University in Boston, Massachusetts.

He has largely focused on hands-on building as a carpenter's apprentice from 2021 to 2022. He worked on remodeling houses and building structural supports for different household amenities. During the summer of 2023 he was federally employed at Diamond Diagnostics Inc. where he worked on refurbishing medical equipment. This made him use critical thinking as to what might be wrong with certain components of the instruments.

Mr. O'Neill is a member of the Northeastern club soccer team and is looking to join engineering clubs in the coming semesters.

Austin R. Philp

Was born in Melbourne Victoria in 2004. However he moved to the United States at the age of 3. He graduated from Ensworth High School in 2023. After a year of engineering he is now studying Psychology at Northeastern University in Boston Massachusetts.

He largely focuses on hands-on building as well as graphic design. He works as a part time video editor for a small streamer, and works as a volunteer around his community building structures. Examples being a greenhouse pathway and garden for the school of the blind, A patio and wheelchair ramp for Room in the Inn, and refurbished a cast iron sign and the area around it. Through all of these projects he has used critical thinking skills, time management skills, and resource management skills.

Mr. Philp is hoping to join the Northeastern Soccer Club in the upcoming semesters as well as several other engineering and audio technology clubs in the future.

APPENDIX A - TEAM CONTRACT

Northeastern University
College of Engineering

Team Contract – Homework D-2

As a TEAM: Create a single contract document that addresses the following:

Contact Information

 List in a table the following for each team member:

 Name

Leo Norton, Rory O'Neill, Austin Philp

 Email

leoznorton@gmail.com, roryjdoneill@gmail.com, austinphilp04@gmail.com

 Phone Number

(303)550-1903, (508)-904-7181, 6155850663

Respect (full sentences)

 What is your definition of work lateness and policy for organized submission?
Have any work done by the deadline given by your group.

 What is your definition of meeting punctuality and procedure for a successful meeting?
Meet +-5 minutes from the agreed meeting time. If you're running late, communicate that.

 What will be the procedure if someone violates these expectations?
You have to bring coffee if you're late. (up for question) ((milk mile?))

Commitment (full sentences)

 What hours do you expect people to be available to meet? Answer questions?
Let's set up a Google calendar with everyone's free time and will communicate from there

 What will your expectations for quality be? / How will you measure this value?
Do everything to the best of your ability and communicate to others if you think they should do better.

 What will be the procedure if someone violates these policies?
That person should improve their work and whoever is the group leader has a conversation with them.

Transparency (full sentence)

 How will your team make decisions? / What will be consensus?
We will communicate and compromise. See what works best for others.

 How will you ensure all information is shared and open to all?
Drop information into the Google Drive folder and text when you do it.

 What will be the procedure if someone feels excluded?
We will communicate with others a lot through text and meetings.

Communication (full sentences)

 Identify the method by which you will primarily communicate with each other.
We will text each other.

 How will you ensure everyone's voice is heard?
We will check up on how

everyones feeling about their contribution before we begin working.

 What will you do when there is a disagreement?
We will identify the issue and figure out a compromise.

 How will you periodically reflect on strengths and issues as a group? (provide a plan)
We will hold meetings and make a chart on our strengths and issues.

Justice (full sentences)

 How will you define equitable contribution?
Do the work assigned to you and make sure all work is assigned equally.

 How will your group work to prevent conflict?
Make sure all assignments are done on time and to the best of your abilities as well as compromising with others.

 What will be the procedure if someone stops contributing?
We will hold an intervention.

Team Goals

 Make a list of 4 or more goals as a team for improving your team skills

- *Be open with others*
- *Communicate effectively*
- *Compromise in decisions*
- *Be timely with your work*

 Make a list of 2 or more goals for each individual

Leo

- *Get assigned work done on time and be on time to meetings*
- *Don't be controlling during projects*

Rory

- *Work well with team*
- *Get all assignments done*

Austin

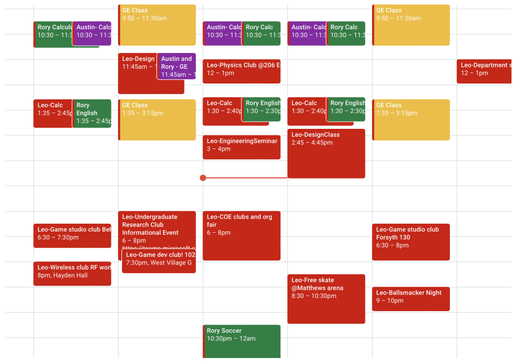
- *Be efficient with completing work*
- *Communicate if having difficulties*

Team Roles

 Make a list of who will be the project manager for the four milestones

1.Leo
2.Rory
3.Austin
3.Leo

Team Calendar:



Leo Norton 1/17/2024

Austin Philp 1/17/2024

Rory O'Neill 1/17/2024

APPENDIX B - EMPATHY MAP

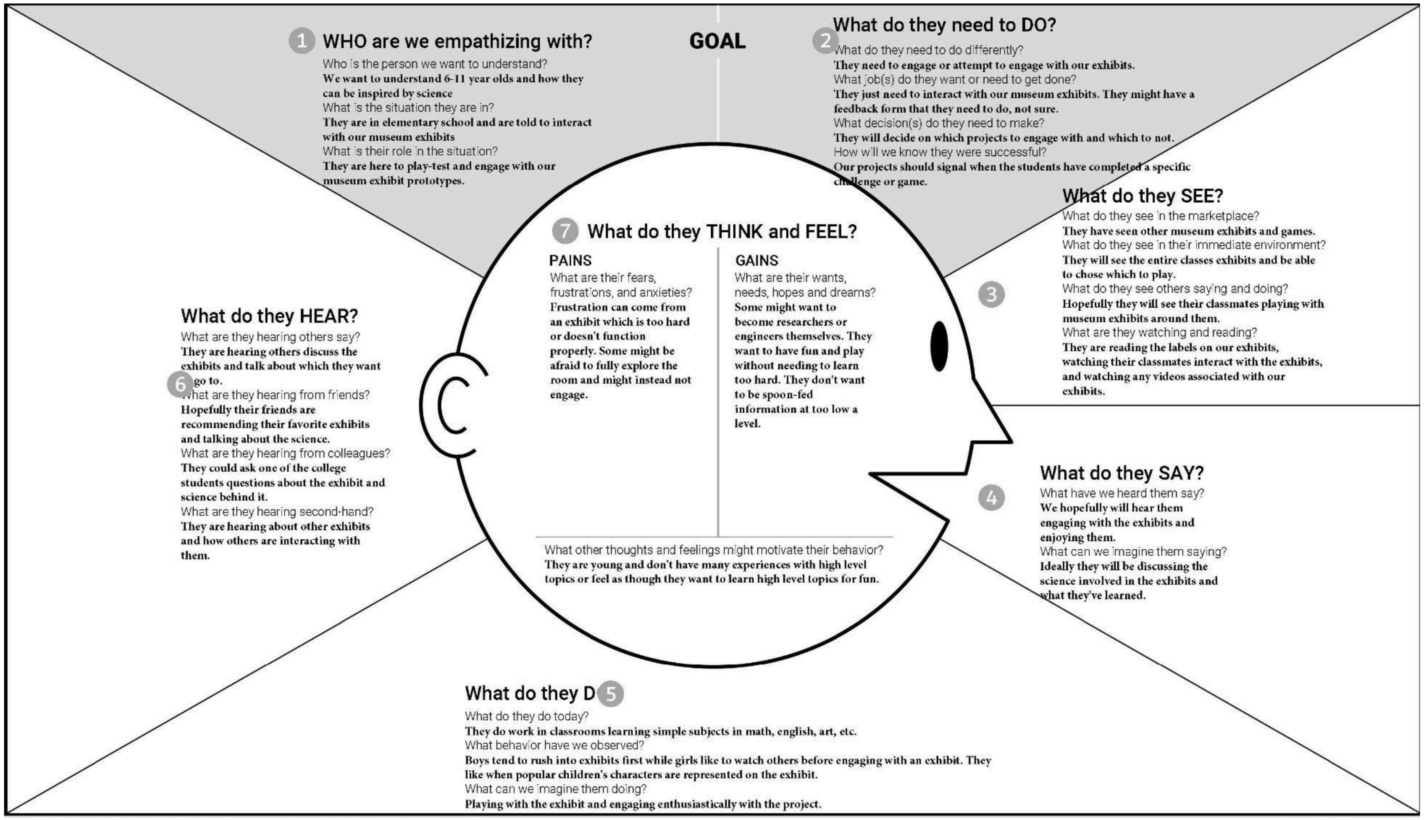


Fig. 2.10. “Empathy map”

APPENDIX C - DECISION ANALYSIS

Our main "musts" include the overall constraints of the assignment. We also added that the project must be feasable and educational. In terms of "wants", interactablility was one of our main goals along with originality and accessibility. "Wants" such as simplicity and theme were less important to us.

Musts		Wind tunnel wind power (Rory)		Energy Flow table(Leo)		Cars Race(Leo)		Clean Water (Austin)		Energy Flow 2 (Austin)		Car Race pt 2 (Rory)	
Under 100$		Yes		Yes		Yes		Yes		Yes		Yes	
Sustainability		Yes		Yes		Yes		Yes		Yes		Yes	
Safe		Yes		Yes		Yes		No		Yes		Yes	
Feasable		Yes		Yes		Yes		Yes		Yes		Yes	
Educational		Yes		Yes		Yes		Yes		Yes		Yes	
Wants	**Weight**	Score	Score *Weight	Score	Score *Weight	Score	Score *Weight	Score	Score *Weight	Score	Score *Weight	Score	Score *Weight
Interactive	8	10	80	7	56	6	48			8	64	6	48
Engaging	7	8	56	7	49	8	56			7	49	7	49
Simple	2	7	14	4	8	6	12			3	6	5	10
Accessible	8	9	72	9	72	9	72			6	48	7	56
Executability	6	8	48	5	30	7	42			5	30	6	36
Durability	6	6	36	5	30	4	24			7	42	8	48

Theme	5	7	35	2	10	10	50			4	20	6	30
Repeatable	7	7	49	10	70	4	28			5	35	9	63
Originality	9	9	81	5	45	5	45			5	45	1	9
Total			471		370		377				339		349
10% of Total			47.1		37		37.7				33.9		34.9

In the end, the only choice that was completely ruled out was the clean water exhibit. We thought that a heating element and water with electricity would create safety hazards. After rating all items, we found the wind tunnel exhibit to be the overall winner by a significant margin.

APPENDIX D - AUTOCAD/SOLIDWORKS DRAWINGS

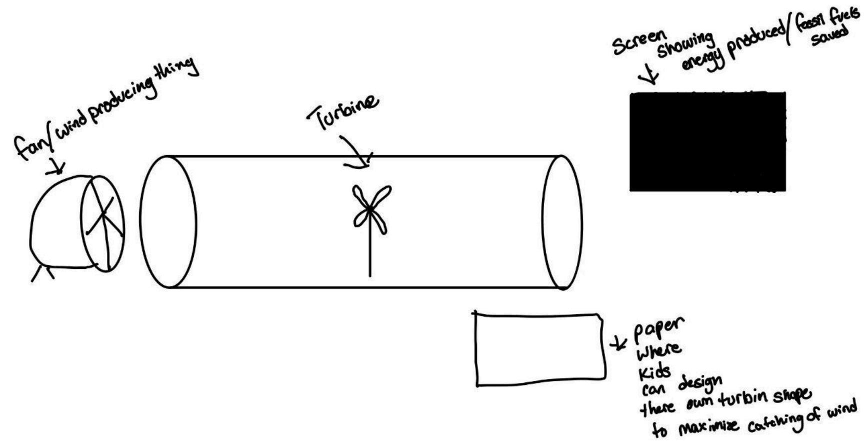


Fig. 2.2. “Original Design Sketch”

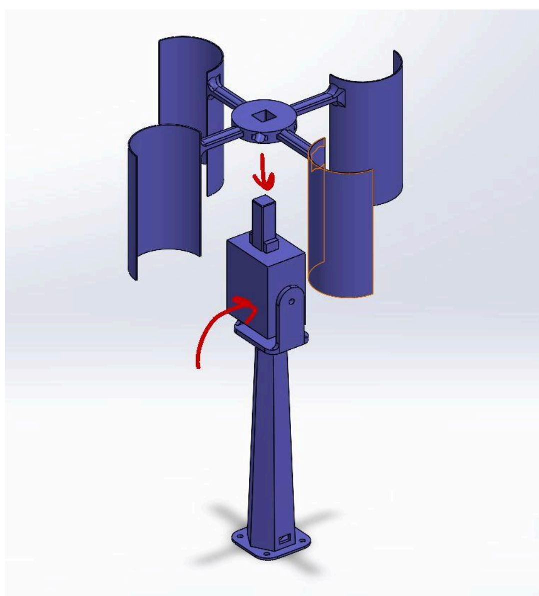


Fig. 2.3. “Savonious Wind Turbine Assembly”

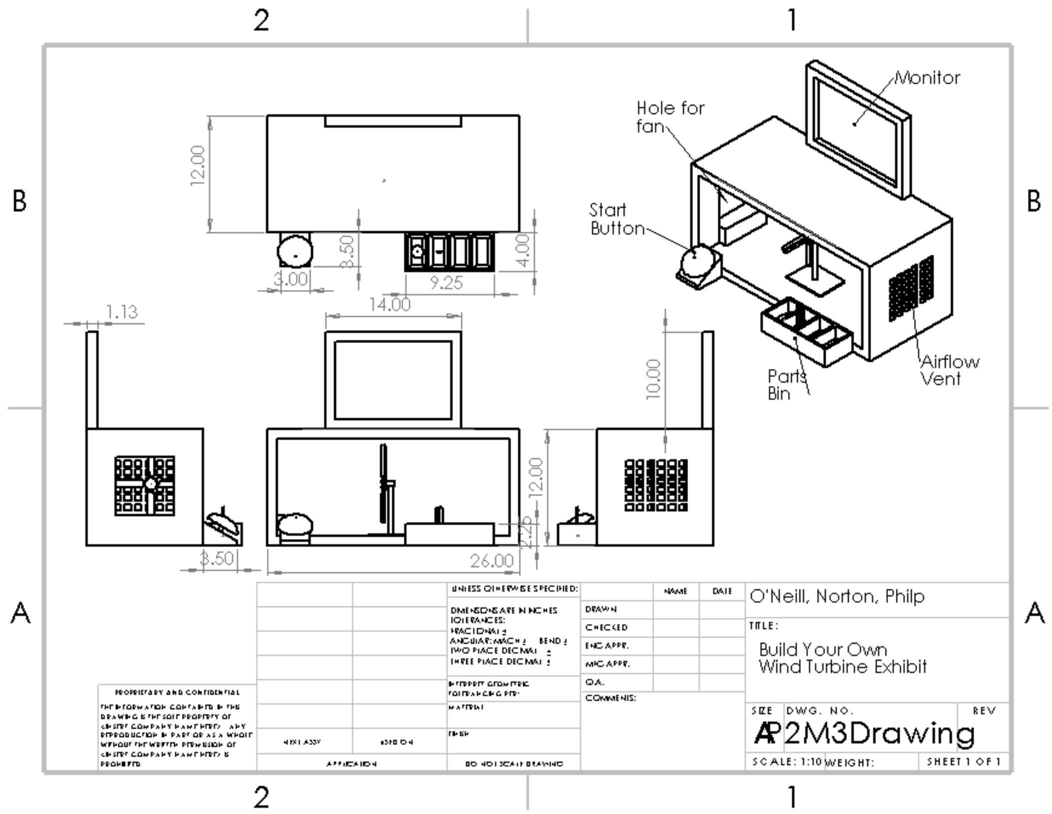


Fig. 2.4. “First Solidworks Sketch”

APPENDIX E - PRODUCT TESTING RESULTS

Requirement	Reasoning	Timing	Method of Evaluation	Data Capture Method	Subject	Measurement Question
Interactive?	Tactile and hands on elements help kids learn concepts and stay on-task	Expo	Both	Observation	Students at the expo	Does the exhibit have kids play with tactile elements for 2 minutes?
Engaging?	Kids need to engage well with any exhibit in order to be motivated to learn from it	Expo	Both	Observation	Ask at S-L	Does the user play the exhibit for the full run time?
3-4 Minute Run Time?	Kids need to be able to finish the exhibit fairly quickly to keep attention and let others play	Expo	Both	Average playtime recorded by Arduino	Students at the expo	Is the timing between 3 and 4 minutes?
Educational?	One of the main criteria for the project was to make it educational and teach about sustainability topics	Expo	Both	Ask the user questions when done with the exhibit	Students at the expo	Can the user answer a simple technical turbine design question?

APPENDIX F - Code Used in Project

Arduino Code

```
#include <Servo.h>  // servo library
#include <FastLED.h>

#define NUM_LEDS 89  // Number of LEDs in your strip
#define DATA_PIN 5   // Pin connected to the data input of the LED strip

const int turbinePIN = A0;
const int relayPIN = 8;
const int servoPIN = 7;
const int startButtonPIN = 12;

//Led Strip Control
CRGB leds[NUM_LEDS];
int currentLED[] = { 0, 45, 60 };

//Servo Control
Servo servo1;

//Gameplay Variables
int startButtonState = 0;
int turbineSelection = 0;
const int numTurbines = 4;
String turbines[numTurbines] = { "Single Blade", "Double Blade", "Quad
Blade", "H-Blade" };
bool canActivateButton = true;
int timer = 0;

//State Machine
enum gameState { start,
                 choose,
```

```
                 build,
                 run,
                 info };
gameState state = start;

void setup() {
  //Digital Pins
  pinMode(relayPIN, OUTPUT);
  pinMode(servoPIN, OUTPUT);
  pinMode(startButtonPIN, INPUT);

  //Servo Setup
  servo1.attach(servoPIN, 900, 2100);  //Connect the servo to pin 9
                                       //with a minimum pulse width of
                                       //900 and a maximum pulse width of
                                       //2100.

  //Led Setup
  FastLED.addLeds<WS2812B, DATA_PIN, GRB>(leds, NUM_LEDS);
  FastLED.setBrightness(200);

  Serial.begin(9600);
}

void loop() {
  //START screen ---------------------------------------------------------
  if (state == gameState::start) {
    Serial.println("Welcome to The Wind Turbine Workshop!");
    Serial.println("Press START to begin");

    while (true) {
      //Setup Functions
      servo1.write(0);
      //rainbowLED();
      //FastLED.show();
```

```
      startButtonState = digitalRead(startButtonPIN);

      if (startButtonState == HIGH) {
        delay(1000);
        break;
      }
      delay(1);
    }
    state = gameState::choose;
  }

  //CHOOSE screen
---------------------------------------------------------
  else if (state == gameState::choose) {
    turbineSelection = -1;
    Serial.println("Press button to choose a turbine design to build!");
    Serial.println("Hold button to select the design");
    //redLED();
    //FastLED.show();

    while (true) {
      servo1.write(180);
      startButtonState = digitalRead(startButtonPIN);

      if (startButtonState == HIGH) {
        if (millis() >= (timer + 2000)) {
          Serial.println("You selected the "+turbines[turbineSelection]+"
turbine!");
          Serial.println("Build the turbine following the directions on
the screen!");
          Serial.println("Press the start button when done!");
          whiteLED();
          FastLED.show();
          delay(2000);
          break;
```

```
      }
      canActivateButton = true;
    }

    if (startButtonState == LOW) {
      if (canActivateButton) {
        canActivateButton = false;
        turbineSelection++;
        if (turbineSelection > numTurbines-1) {
          turbineSelection = 0;
        }
        Serial.println(turbines[turbineSelection]+" selected");
        Serial.println("Hold button to start!");
      }
      timer = millis();
    }
    delay(1);
  }
  state = gameState::build;
}

//BUILD screen ---------------------------------------------------------
else if (state == gameState::build) {
  while (true) {

    servo1.write(180);
    startButtonState = digitalRead(startButtonPIN);
    if (startButtonState == HIGH) {
      delay(1000);
      break;
    }
    delay(1);
  }
  state = gameState::run;
}
```

```
  //RUN screen --------------------------------------------------------
  else if (state == gameState::run) {
    digitalWrite(relayPIN, HIGH);
    float voltageSum = 0;
    for (int i = 0; i < 300; i++) {
      //setup functions
      //windyLED();
      //if (millis() % 25 == 0) {
        //FastLED.show();
      //}
      int sensorValue = analogRead(turbinePIN);

      // print out the value you read:
      voltageSum = voltageSum + sensorValue;
      Serial.println(voltageSum / i + 1);
      Serial.println(sensorValue);
      for (int j = 0; j < 100; j++) {
        servo1.write(0);
        delay(1);
      }
    }
    Serial.println("Your average voltage is: " + String(voltageSum /
300));
    state = gameState::info;
  }

  //INFO screen --------------------------------------------------------
  else if (state == gameState::info) {
    Serial.println("A " + turbines[turbineSelection] + " is good for
reasons!");
    Serial.println("Press START to continue...");
    //redLED;
    //FastLED.show();
```

```
    digitalWrite(relayPIN, LOW);
    while (startButtonState == LOW) {
      startButtonState = digitalRead(startButtonPIN);
      delay(1);
    }
    state = gameState::start;
  }
}

void windyLED() {
  for (int i = 0; i < NUM_LEDS; i++) {
    leds[i] = CRGB::Black;
  }
  for (int i = 0; i < 3; i++) {
    leds[currentLED[i]] = CRGB::White;
    leds[currentLED[i]+1] = CRGB::White;
    leds[currentLED[i]+2] = CRGB::White;
    leds[currentLED[i]+3] = CRGB::White;
  }
  currentLED[0] += 1;
  currentLED[1] -= 1;
  currentLED[2] += 1;
  if (currentLED[0] == NUM_LEDS/3) {
    currentLED[0] = 0;
  }
  if (currentLED[1] == NUM_LEDS/3) {
    currentLED[1] = 2*NUM_LEDS/3;
  }
  if (currentLED[2] == NUM_LEDS) {
    currentLED[2] = 2*NUM_LEDS/3;
  }
}

void rainbowLED() {
  static uint8_t hue = 0;
```

```
  static int offset = 0;

  // Shift the hue offset for rotation
  hue += 2;

  // Move the rainbow pattern by shifting the LED indices
  offset++;
  if (offset >= NUM_LEDS) {
    offset = 0;
  }

  for (int i = 0; i < NUM_LEDS; i++) {
    leds[(i + offset) % NUM_LEDS] = CHSV(hue + (i * 255 / NUM_LEDS), 255,
255); // Gradually shift hue for each LED
  }
}

void redLED() {
  for (int i = 0; i < NUM_LEDS; i++) {
    leds[i] = CRGB::Red;
  }
}

void whiteLED() {
  for (int i = 0; i < NUM_LEDS; i++) {
    leds[i] = CRGB::White;
  }
}
```

Unity Code

using System.Collections;

using System.Collections.Generic;

```
using UnityEngine;

using UnityEngine.SceneManagement;



public class NextScene : MonoBehaviour

{

    void OnMessageArrived(string msg)

    {

        Debug.Log(msg);

        if (msg == "Press button to choose a turbine design to build!")

        {

            SceneManager.LoadScene("Select Screen", LoadSceneMode.Single);

        }

    }

    // Invoked when a connect/disconnect event occurs. The parameter 'success'

    // will be 'true' upon connection, and 'false' upon disconnection or
```

```
    // failure to connect.
    void OnConnectionEvent(bool success)
    {
        Debug.Log(success ? "Device connected" : "Device disconnected");
    }


    // Update is called once per frame
    void Update()
    {
#if UNITY_EDITOR
        KeyCode quitKey = KeyCode.J;
        KeyCode nextKey = KeyCode.Space;
#else
        KeyCode quitKey = KeyCode.Escape;
        KeyCode nextKey = KeyCode.Space;
```

```
#endif

        if (Input.GetKeyDown(quitKey))
        {
            Application.Quit();

            Debug.Log("Quit Game.");
        }

        if (Input.GetKeyDown(nextKey))
        {
            SceneManager.LoadScene("Select Screen", LoadSceneMode.Single);
            Debug.Log("Next Scene.");
        }
    }
```

}

APPENDIX G - WIRE DIAGRAMS FOR ELECTRONICS

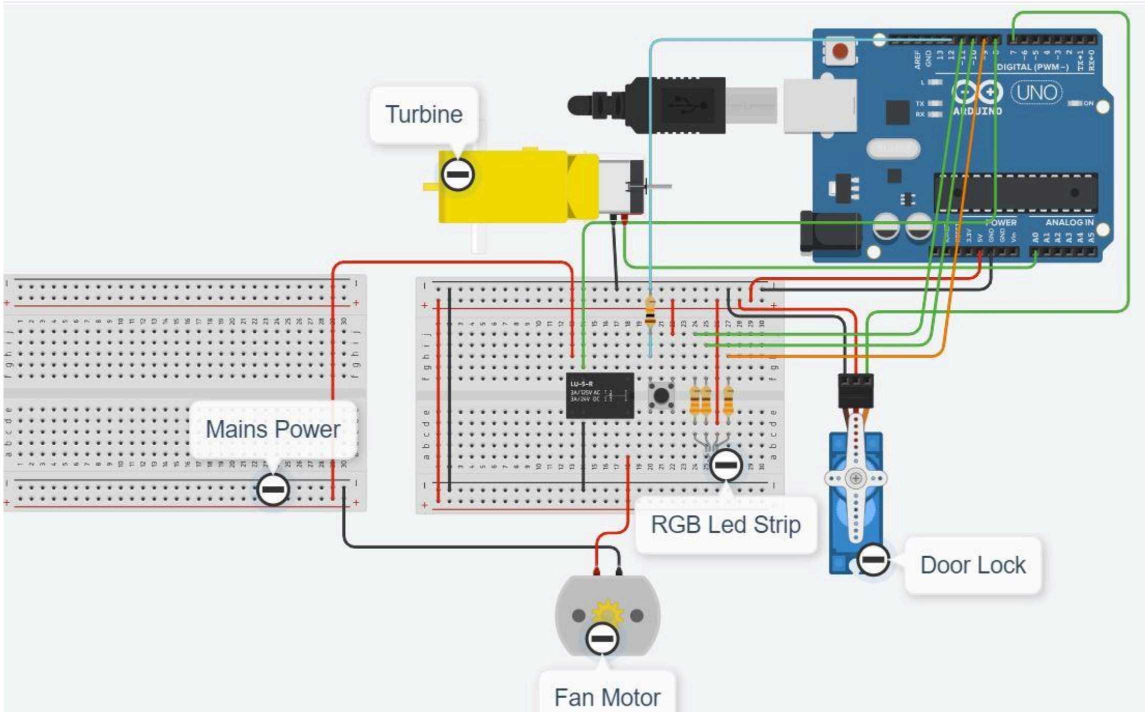


Fig. 2.5. “Wire Diagram”

APPENDIX H - PHOTO LOG

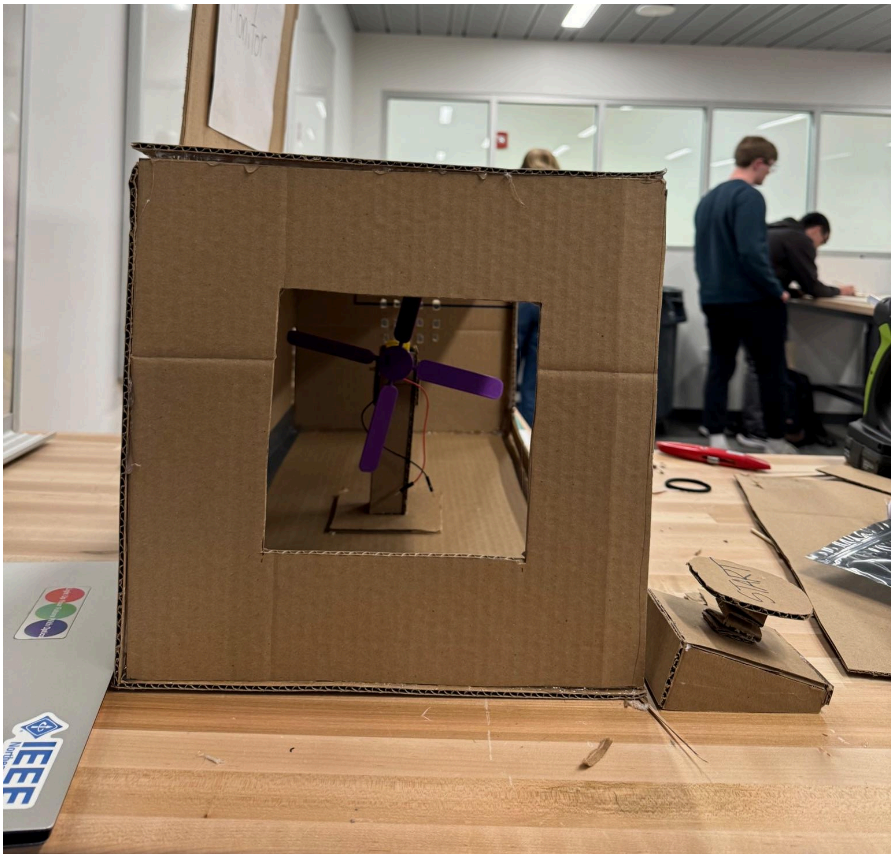


Fig. 2.6. “Left Side Cardboard Mockup”

Fig. 2.7. “Front cardboard mockup”

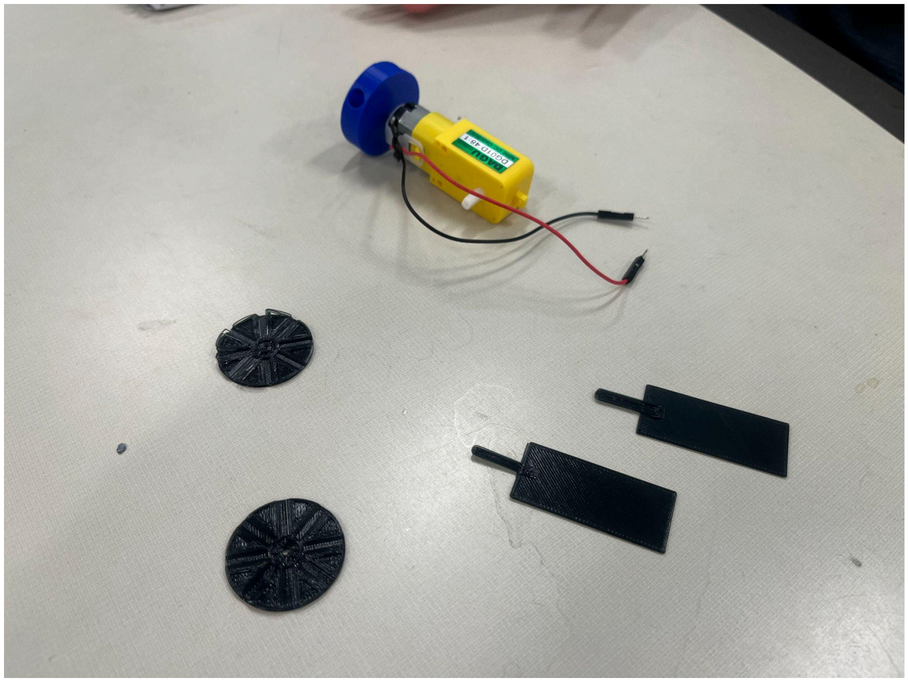


Fig 2.8. “Original blade and hub design”

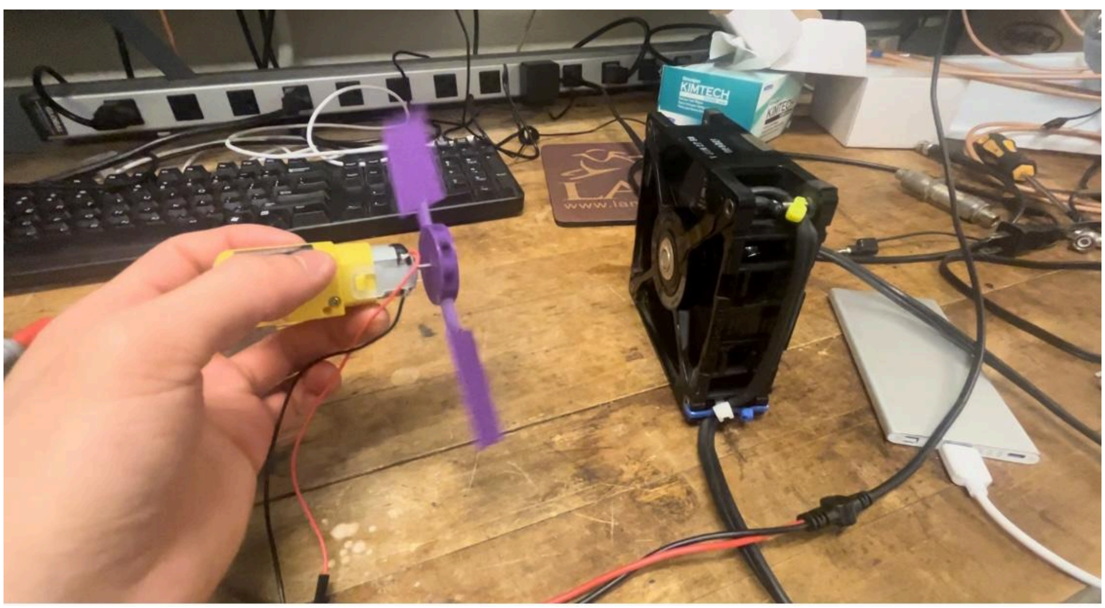


Fig 2.9. “Testing to see if fan will spin the turbine and produce electricity”

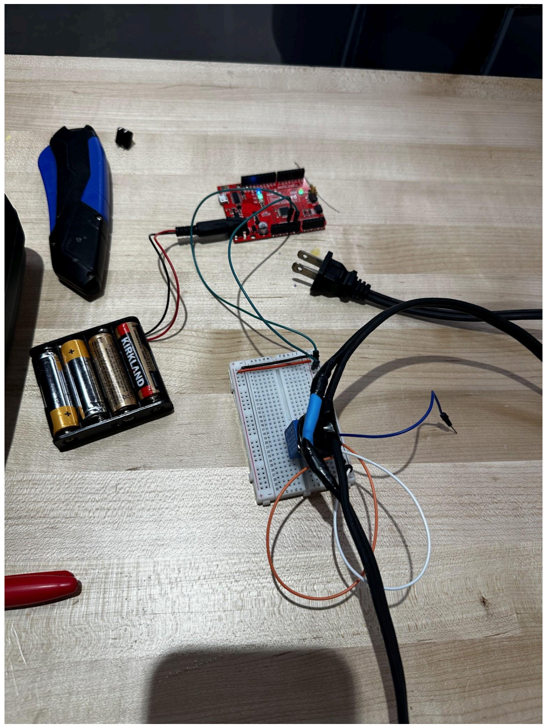


Fig. 3.0. “Relay wiring for fan”

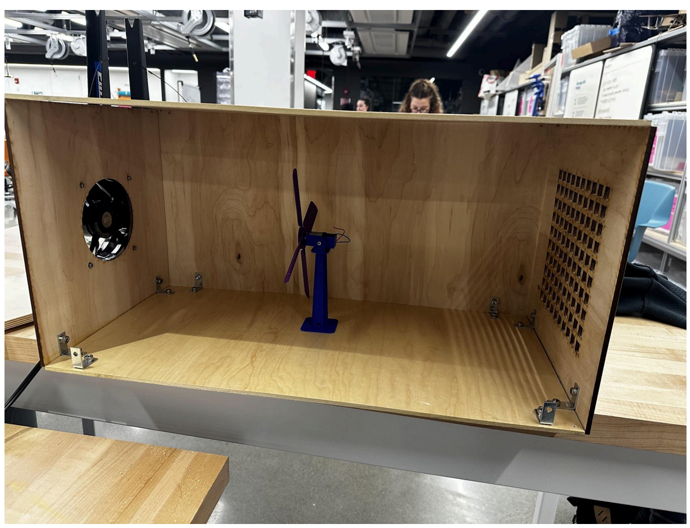


Fig 3.1. “Partial construction of the wind tunnel”

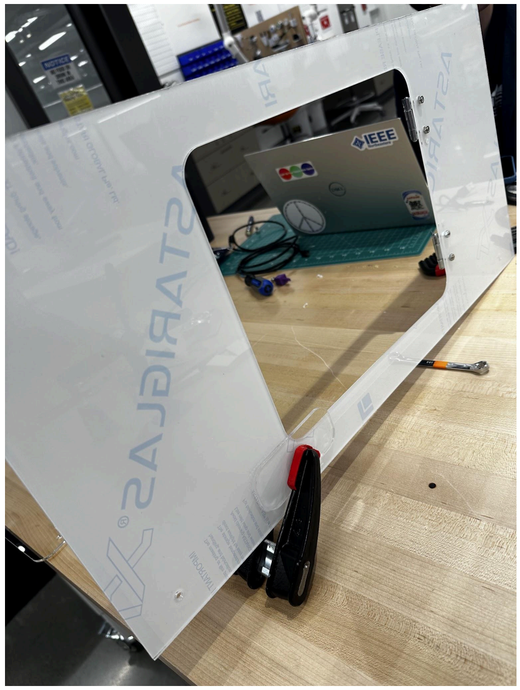


Fig. 3.2. “Laser cut door for the front of the wind tunnel”

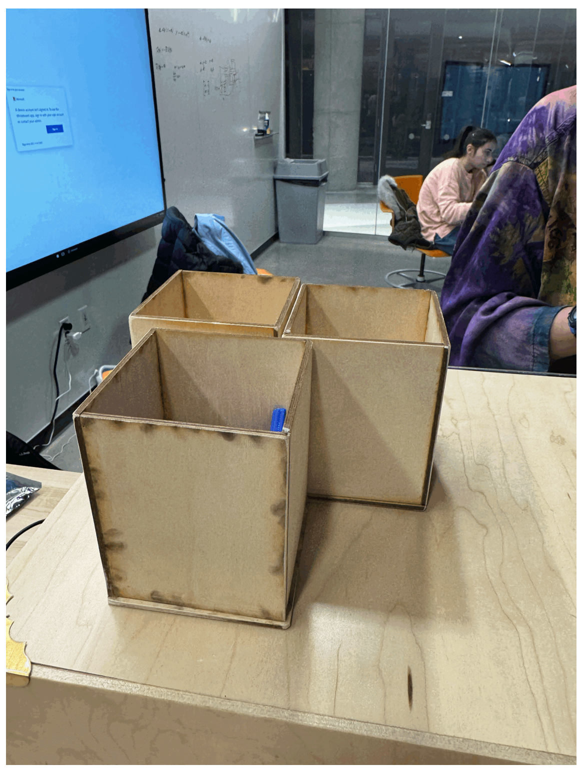


Fig. 3.3. “Boxes for the various blades and hubs”

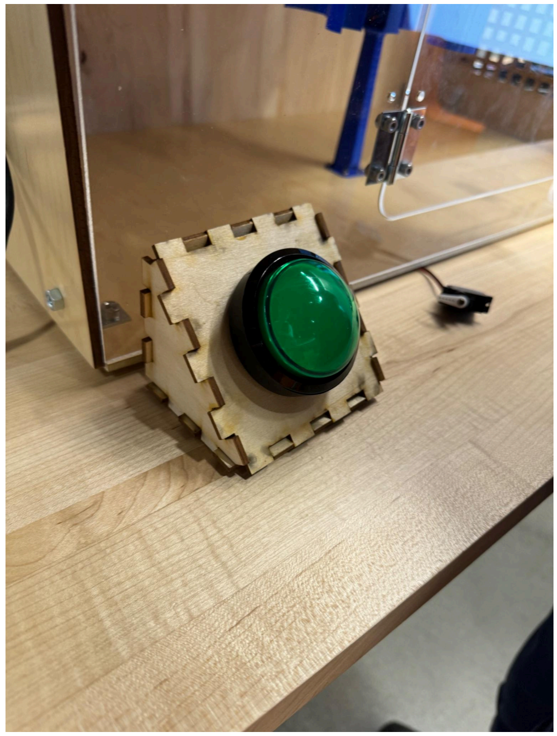


Fig. 3.4. “The encasing for the button”

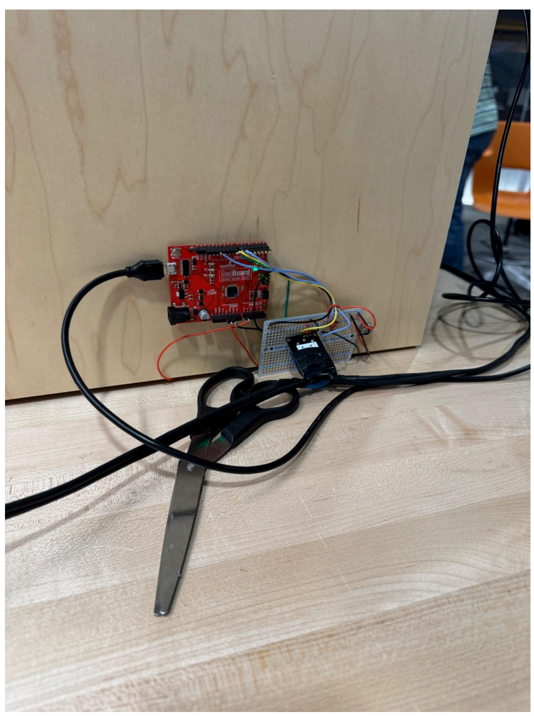


Fig. 3.5. “The finished redboard with wires strapped to the back of the exhibit”

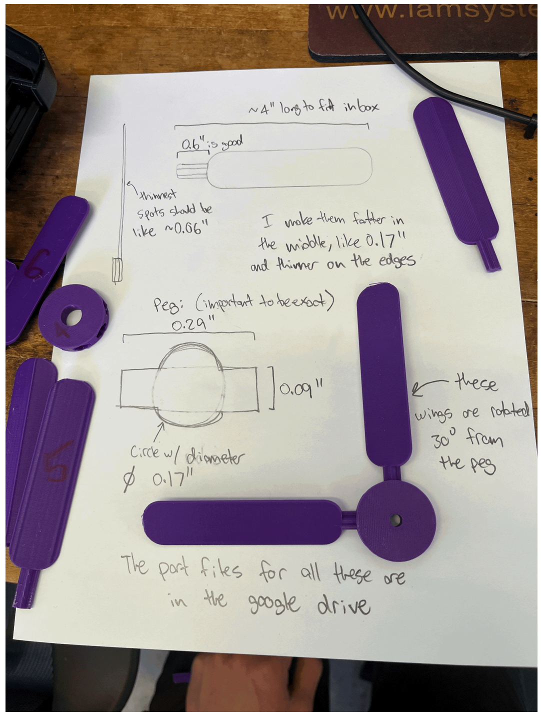


Fig. 3.6. “First design for the turbine blades”

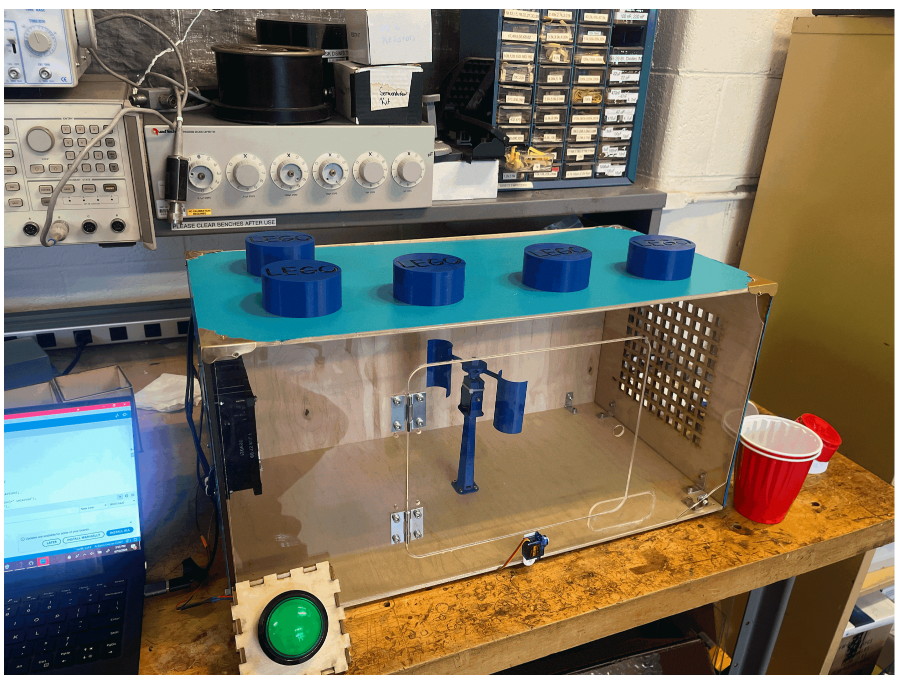


Fig. 3.7. “Design before lego brick caps were vinyl wrapped”

Fig. 3.8. “Fully put together exhibit at expo”

APPENDIX I - GUI AND VISUAL LAYOUT

POSTER BOARD:

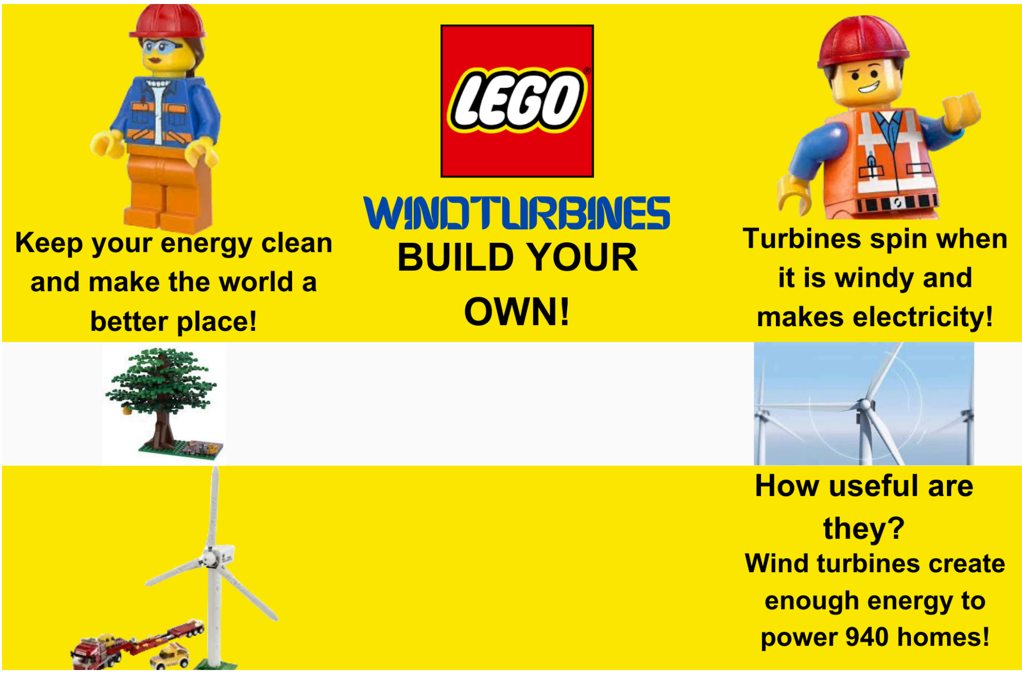


Fig. 3.9. "Trifold Design"

Fig. 4.0. "Original Storyboard"

UNITY UI:

Fig. 4.1. "Unity Start Screen"

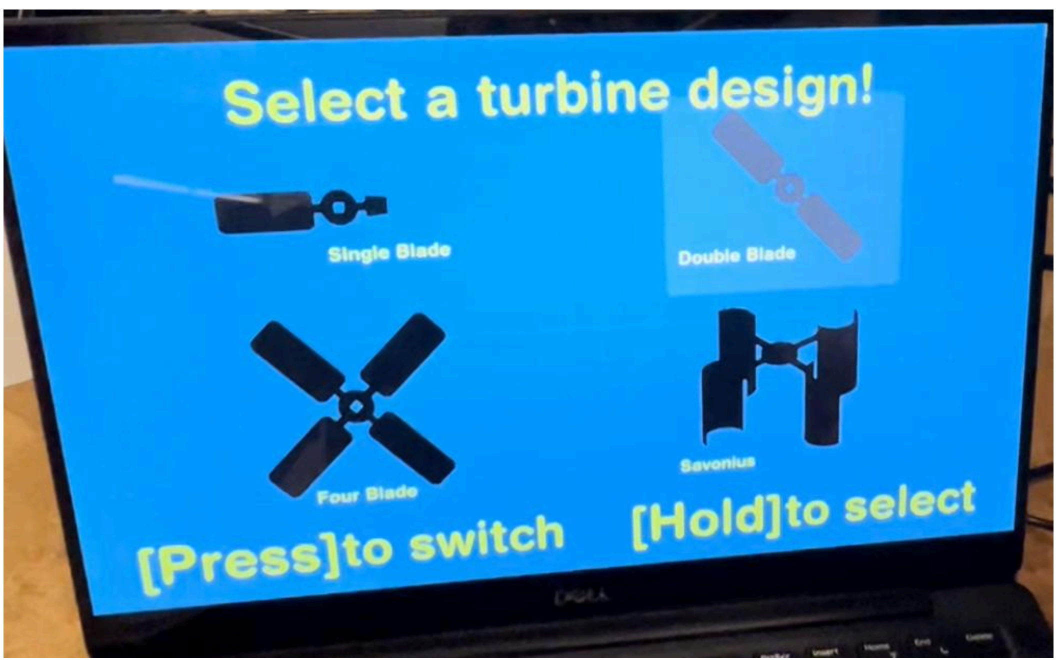


Fig. 4.2. "Unity Selection Screen"

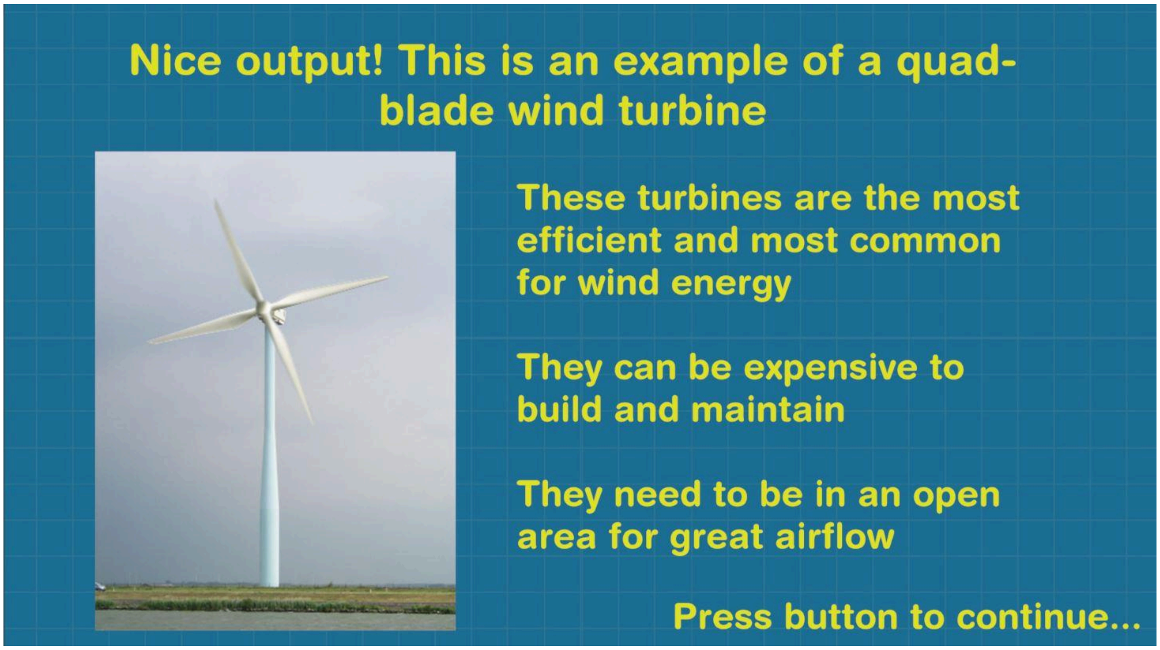
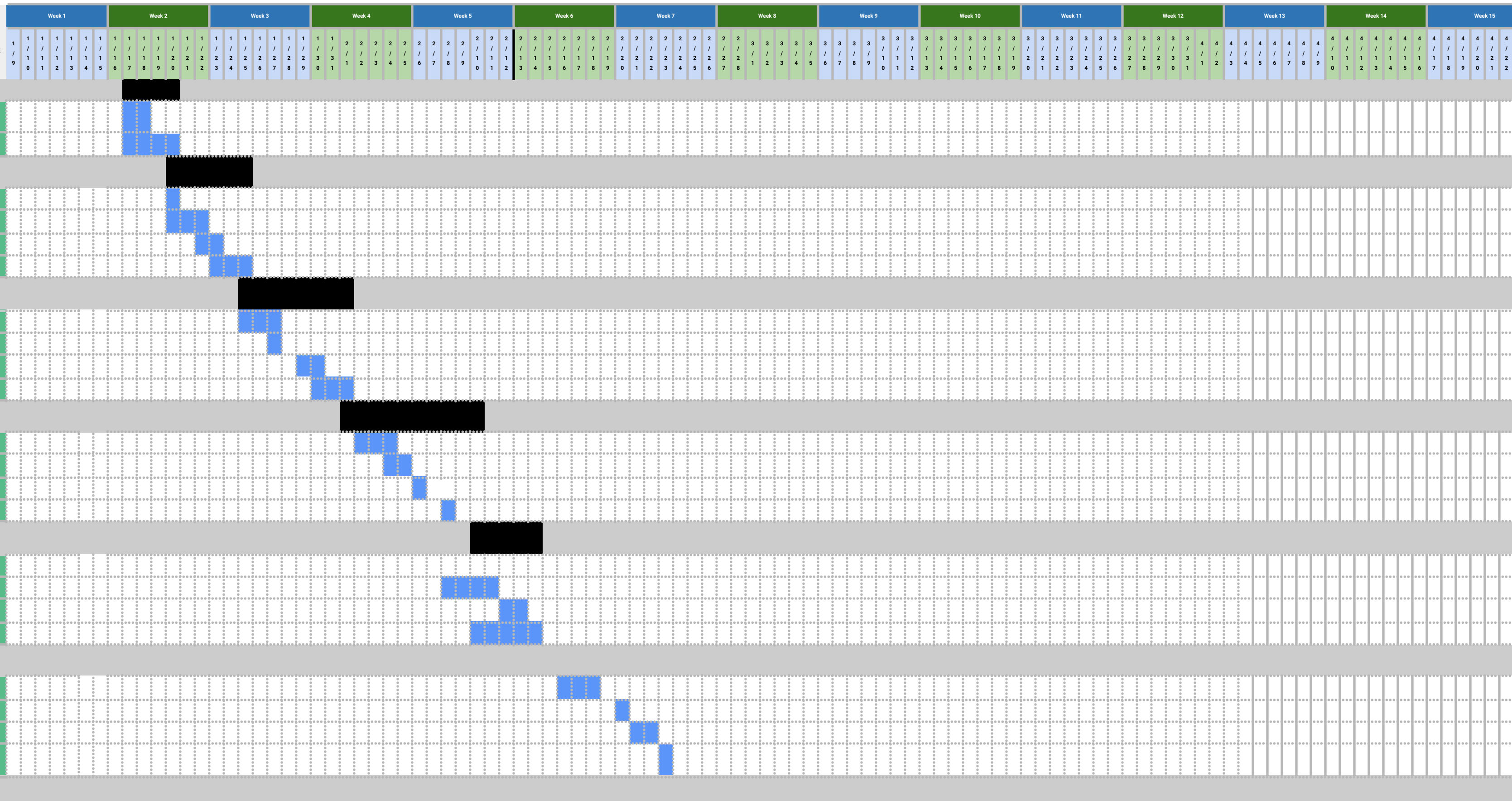


Fig. 4.3. “Unity Four Blade Info Screen”

APPENDIX J - FINAL GANTT CHART

TASK TITLE	TASK OWNER	START	END	EXPECTED DURATION	PCT OF TASK COMPLETE
D2-Milestone 0	**All**	**1/17**	**1/20**		**100%**
Discuss Team Contract elements	all	1/17	1/18	2hr	100%
Prepare Team Contract	all	1/17	1/20	1hr	100%
P1-Milestone 1	**PM 1**	**1/20**	**1/25**		**100%**
Task 1 - Individual Drawings	All	1/20	1/20	2hrs	100%
Task 2 - Memo	All	1/20	1/22	2hrs	100%
Task 3 - Empathy Chart	All	1/22	1/23	1hr	100%
Task 4 - Gant Chart	All	1/23	1/25	1hr	100%
P1-Milestone 2	**PM 2**	**1/25**	**2/1**		**100%**
Cad design	All	1/25	1/27	2hr	100%
Mentor Meeting	All	1/25	1/29	0.5hr	100%
Bridge design and discussion	All	1/29	1/30	0.5hr	100%
Memo	All	1/30	2/1	2hr	100%
P1-Milestone 3	**PM 3**	**2/1**	**2/10**		**100%**
Bridge design	All	2/1	2/5	1hr	100%
Bridge Building	All	2/4	2/7	3hr	100%
Bridge Testing	All	2/8	2/9	1hr	100%
Memo	All	2/6	2/10	2hr	100%
P1-Milestone 4	**PM 4**	**2/10**	**2/14**		**100%**
Task 1 (Use full descriptions)	All	2/10	2/9	2hr	100%
Task 2	All	2/8	2/11	8hr	100%
Task ...	All	2/12	2/13	1hr	100%
Task n	All	2/10	2/14	12hr	100%
P2-Milestone 1	**PM 1**	**2/22**	**3/4**		**100%**
Individual Research	All	2/22	2/27	2hr	100%
Meeting	All	2/26	3/1	2hr	100%
Memo writing	All	3/2	3/3	2hr	100%
Presentation	Austin	2/28	3/4	10min	100%
P2-Milestone 2	**PM 2**	**3/4**	**3/11**		**100%**



Individual Research and drawing	All	3/4	3/6	4hr	100%
Meeting	All	3/5	3/8	2hr	100%
Design Notebook	All	3/7	3/10	2hr	100%
Memo writing	All	3/9	3/10	3hr	100%
Presentation	Leo	3/7	3/11	3hr	100%
P2-Milestone 3	**PM 3**	**3/11**	**3/25**		**100%**
Cad design	All	3/11	3/20	2hr	100%
Cardboard Prototype	All	3/19	3/22	4hr	100%
Memo	All	3/21	3/24	3hr	100%
3D Printing	All	3/23	3/24	2hr	100%
Presentation	Rory	3/21	3/25	10min	100%
P2-Milestone 4	**PM 4**	**3/25**	**4/1**		**100%**
Mentor Meeting	All	3/25	3/27	1hr	100%
Meeting	All	3/26	3/29	2hr	100%
Feedback and planning	All	3/30	3/31	2hr	100%
Presentation	All	3/28	4/1	10min	100%
P2-Milestone 5	**All**	**4/1**	**4/19**		**100%**
Buidling	All	4/1	4/14	2hr	100%
Coding	All	4/13	4/16	4hr	100%
hardware	All	4/17	4/18	3hr	100%
memo writing	All	4/15	4/19	2hr	100%
P2-Milestone 6	**All**	**4/19**	**4/25**		**0%**
Make video	All	4/19	4/20	2hr	0%
Main Event	All	4/19	4/22	2hr	0%
Memo writing	All	4/23	4/24	2hr	0%
Presentation	All	4/21	4/25	10min	0%
P2-Milestone 7	**All**	**4/1**	**4/22**		**0%**
Technical Report writing	All	4/1	4/17	2hr	0%
Peer feedback	All	4/16	4/19	2hr	0%
Reflection	All	4/20	4/21	2hr	0%
Presentation	All	4/18	4/22	10min	0%
P2-Milestone 8	**All**	**4/22**	**5/3**		**0%**
Report Writing	All	4/22	4/28	2hr	0%
Task 2	All	4/27	4/30		0%
Task ...	All	5/1	5/2		0%
Task n	All	4/29	5/3		0%

APPENDIX K - FINAL BUDGET

○

Item	Unit Value	Units	Qty	Value	Cost	Source
Wood	$7.16	ea	4	$28.00	$28.00	EXP
Button	$0.00	ea	1	$0	$0	Fyelic
Acrylic	$7.00	ea	2	$14	$14	EXP
Monitor	$0.00	ea	1	$0	$0	sourced (Rory's)
Brackets	$27.00	ea	1	$27	$27	Store
Motor	$0.00	ea	1	$0	$0	kit
3d-prints	$0.00	ea	N/A	$0	$0	Wireless club
Fan	$0.00	ea	1	$0	$0	Sourced (leo)
…	…	…	…	…	…	…
			Totals	$69.00	$69.00	

APPENDIX L - Project Hours Log

	Rory	Austin	Leo	Team Members 4 (N/A)	Total Work Hours
Milestone 0					
Discuss MS0 Topics	1.5	1.5	1.5		4.5
Finalize Team Contract	0.5	0.5	0.5		1.5
Totals	2	2	2		6
P1- Milestone 1					
Mentor Meeting	0.5	0.5	0.5		1.5
Research and design	3	2	2		7
P1-M1	1	1	2		4
Task ...					0
Task n					0
Totals	4.5	3.5	4.5		12.5
P1-Milestone 2					
Mentor Meeting	0.5	0.5	0.5		1.5
Pasta Bridge	4	3	4		11
P1-M2					0
Task n					0
Totals	4.5	3.5	4.5	0	12.5
P1-Milestone 3					
Bridge design	2	2	2		6
Bridge Building	3	3	3		9

Bridge Testing	1	1	1		3
Memo	1	1	1		3
Totals	7	7	7	0	21
P1-Milestone 4					
Bridge design	1	1	1		3
Meeting	2	2	2		6
Bridge Testing	2	2	2		6
Memo	2	2	2		6
Totals	7	7	7	0	21
P2-Milestone 1	PM				
Individual Research			2		2
Meeting			0.5		0.5
Memo writing			3		3
Presentation			0		0
Totals	0	0	5.5	0	5.5
P2-Milestone 2			PM		
Individual Research and drawing	2	2	2		6
Meeting	1	1	1		3
Design Notebook	1	1	2		4
Memo writing	2	2	3		7
Presentation			4		4
Totals	6	6	12	0	24
P2-Milestone 3		PM			
Cad design	2	1	2		5
Cardboard Prototype	4	3	4		11

Memo	2	2	2		6
3D Printing	2	1	3		6
Presentation	2	0	0		2
Totals	12	7	11		30
P2-Milestone 4					PM
Meeting	1	1	1		3
Construction	9	6	10		25
Memo	1	1	3		5
Presentation	0	2	0		2
Misc.	1	2	1		
Totals	12	12	15	0	39
P2-Milestone 5					
Building	2	1	6		9
Coding		4	9		13
Hardware	3	0	3		6
Memo	2	1	1		4
Totals	7	6	19	0	32
P2-Milestone 6					
Final Touches			6		6
Make video			0.5		0.5
Main Event			3		3
Memo writing			0.5		0.5
Totals	0	0	10	0	10
P2-Milestone 7					
Technical Report writing			7		7

Peer feedback			0.5		0.5
Reflection			1		1
Presentation					0
Totals	0	0	8.5	0	8.5
P2-Milestone 8					
Report Writing			10		10
Task 2					0
Task ...					0
Task n					0
Totals	0	0	10	0	10