Northeastern University
College of Engineering

Cornerstone of Engineering I & II
Spring 2025 MWT

Biogas: Fart to Fuel

SUBMITTED BY:

Team One
Biogas

PREPARED BY:

Eva Mescher
Jonathan Chan
Joseph Afflitto
Caroline DiMaio

Report Submitted: **4/22/2025**

ABSTRACT

Our team was tasked with designing an interactive museum exhibit aimed at educating elementary school students through hands-on learning, with a focus on renewable energy and sustainability. The exhibit needed to be engaging, intuitive, and informative, while also adhering to strict constraints around tabletop dimensions, ease of transport and setup, child safety, and a $100 budget cap. This technical report outlines the engineering design process our team followed to develop a fully functional exhibit that met these requirements.

In response to this challenge, we created a two-stage, farm-themed biogas game that introduces students to the concept of sustainable energy production through biogas. The first stage is a solo waste-sorting game where players identify and collect “good” waste suitable for biogas production, using a monitor display synced with descending LED lights and a moveable basket. In the second stage, players collaborate in a multiplayer setup: one participant cranks to simulate energy generation, while the other adjusts a temperature dial to maintain optimal biogas production conditions. Our solution was well received during the expo, particularly for its immersive storyline and engaging gameplay mechanics that taught users the practical use of biogas production in everyday energy-reliant needs.

LIST OF FIGURES

JONATHAN CHAN

1 INTRODUCTION

1.1 PROBLEM STATEMENT

As the global demand for clean energy continues to grow, it is increasingly important to introduce sustainability concepts to children at an early age. Students between the ages of 6 and 11 are at a critical stage of cognitive development, where interactive and meaningful experiences can shape long-term values and habits. Unfortunately, many current approaches to teaching young students about renewable energy either lack depth or fail to engage them beyond surface-level interest. To address this, our team proposes the development of an interactive learning experience that introduces the concept of biogas as a renewable energy source in a way that is both educational and entertaining. The goal is to immerse students in the process of how biogas is collected, generated, and used, emphasizing its role in building a sustainable future.

This experience will use playful design elements, responsive mini-games, and colorful visuals to maintain attention and stimulate curiosity, all within a 1–2 minute interaction period suited for high-traffic educational settings such as museums or classrooms. The design must be universally accessible—accommodating different physical, cognitive, and language abilities—while also being cost-effective, meaning it can be produced and maintained with limited resources without sacrificing durability or learning impact. By creating a hands-on, feedback-rich environment, we aim to empower students with knowledge that not only sticks but also inspires future action toward environmental responsibility.

1.2 STAKEHOLDERS

The key stakeholders for this project are the students, teachers, families, and school staff from Beachmont Veterans Memorial School and Garfield Middle School in the Boston area. These schools are taking part in a larger exhibit expo where the project will be presented to a wide audience, including students, educators, parents, and community members. The expo is a chance for everyone to engage with the exhibit and learn more about renewable energy—specifically, how biogas works and why it's important.

The primary users are students between the ages of 6 and 11. They are at a stage where hands-on, playful learning is especially helpful. Teaching them about biogas—a clean energy source made from organic waste—can help them build an early understanding of how energy works and why sustainability matters. This type of learning can encourage students to think about the environment, their own habits, and how science can be used to solve real-world problems.

The secondary users include teachers, parents, and family members. Teachers can use the exhibit to support science and environmental lessons, while parents and family members can help reinforce what students learn during the expo. These groups benefit from better educational tools and from seeing students excited about learning. The exhibit also gives families a chance to learn more about renewable energy together, possibly encouraging more sustainable habits at home.

Other important stakeholders are school staff, administrators, and the broader community. These groups are interested in promoting STEM education, encouraging environmental responsibility, and providing engaging learning opportunities that are accessible to all students. We kept all of these users in mind during the design process—making sure the exhibit is fun, informative, easy to use, cost-effective, and inclusive to a wide range of learning and physical needs. Feedback from educators and students helped us shape our design goals, and more about that process will be explained in the Methodologies section.

1.3 REQUIREMENTS

The exhibit must meet several physical, functional, and educational requirements to ensure its success at the exhibit expo.

Physical Requirements:

The exhibit must fit within a 28"D x 36"W space, including a trifold that explains the biogas process. It should also incorporate age-appropriate educational text about biogas to ensure that students understand the core concepts. Additionally, the exhibit must include two interactive components that engage users and help them learn about the biogas process.

The exhibit must react to user inputs, such as touch or motion, to keep users engaged. It should also stay within a $100 budget, covering the cost of materials and technology.

Transportability:

The exhibit should be easy to transport, fitting into a provided storage bag (27.6"L x 13.8"W x 16.5"H). Two individuals should be able to carry the exhibit comfortably. The design must allow for quick setup and breakdown, taking no longer than 15 minutes in total.

Educational and Functional Requirements:

The exhibit needs to engage students aged 6–11 and help them retain information about renewable energy, particularly biogas. It should be designed to be accessible to users with physical, cognitive, or language barriers, ensuring that all students can interact with the exhibit effectively.

The information provided must be accurate and simplified for young learners. The exhibit should include feedback mechanisms, such as visual or auditory responses to user actions, to enhance the learning experience. Lastly, the exhibit should highlight the environmental benefits of biogas and its role in sustainability.

These requirements provide a clear framework for designing an effective, accessible, and practical exhibit for the expo.

1.4 ETHICAL CONSIDERATIONS

Ethical considerations, particularly Value Sensitive Design (VSD), guided the development of this exhibit. VSD ensures that the design addresses the values of all stakeholders, promoting inclusivity and positive social impact.

A key focus was accessibility, ensuring the exhibit could be used by students with physical, cognitive, or language barriers. Design elements like adjustable text size, auditory cues, and careful attention to the height of the exhibit were incorporated to support diverse learning needs. The exhibit is designed to be easily accessible by multiple players at once, allowing students to interact together and collaborate.

The exhibit was designed to be physically engaging and visually appealing, with a tilted orientation to draw students' attention. The structure is surrounded by walls filled with educational content and graphics, creating an immersive experience. The content is scientifically accurate but age-appropriate, providing information about biogas and renewable energy without oversimplifying key concepts.

Additionally, the environmental impact of the materials was carefully considered, aiming to use eco-friendly options and reduce waste. The exhibit encourages students to think critically about sustainability and their role in protecting the environment, fostering an eco-conscious mindset.

These ethical principles were central to both the design and the educational objectives, ensuring the exhibit is engaging, accessible, and environmentally responsible.

1.5 WHAT IS BIOGAS?

Biogas is a renewable energy source produced by the breakdown of organic matter, such as food waste, animal manure, and plant material, in an environment without oxygen. This process, called anaerobic digestion, occurs when bacteria decompose organic waste, producing a mixture of gases, primarily methane and carbon dioxide.

The key stage in biogas production is the methane generation phase, where microorganisms break down organic materials into methane gas, which can then be captured and used as a clean fuel. Biogas can be used for heating, electricity generation, and even as a vehicle fuel.

Biogas is an environmentally friendly alternative to fossil fuels, as it reduces greenhouse gas emissions and supports waste management by turning organic waste into valuable energy. It helps reduce reliance on non-renewable resources and provides a sustainable way to produce energy, making it an important part of the transition to renewable energy systems.

1.6 SCOPE

This report focuses on the engineering design process behind the development of the interactive exhibit aimed at teaching students about biogas and renewable energy. It will explore the steps taken to define the design requirements, the challenges faced, and the solutions developed throughout the process. Key aspects such as design priorities, testing, and refinement will be discussed in detail.

Additionally, the report will assess the overall effectiveness of the exhibit in terms of user engagement, educational impact, and enjoyment. It will provide insights into the successes and areas for improvement based on both design objectives and user feedback.

2 BACKGROUND

While formal education through traditional schooling remains the norm, maintaining students' interest and motivation continues to be a challenge. Informal learning environments, like museums, offer an alternative path to education—one that promotes curiosity through hands-on, engaging experiences. Unlike classroom instruction, which often relies on passive learning, museums provide interactive, physical exhibits that invite exploration and discovery.

A great example of this is the Museum of Science in Boston, where exhibits are designed to be both informative and entertaining. Features such as tactile buttons, motion-based elements, and life-size models help translate abstract ideas into something kids can physically interact with. Research by Shaby, Assaraf, and Tal [18] supports this approach, finding that student engagement increases when exhibits include opportunities for group participation, familiar elements, and social interaction.

Accessibility is another key consideration in exhibit design. Many effective exhibits are built with inclusivity in mind—screens are placed at reachable heights and angled for visibility, and interactive elements are made large and easy to operate. Kiriyama and Sato [19] highlight how thoughtful exhibit mechanics and layout choices directly affect user behavior and experience. Their evaluation of installations such as “Arithmetik Garden” and “Pool of Fingerprints” shows that design decisions involving space, movement, and responsiveness are essential to meaningful visitor interaction.

Beyond physical access, inclusive design must also consider gender. Studies have shown that STEM exhibits are often unintentionally skewed toward boys, discouraging girls from participating. The Exhibit Design for Girls’ Engagement (EDGE) framework addresses this by emphasizing three main ideas: the use of visual, person-based labels to guide interaction; the inclusion of familiar and inviting objects to make kids feel at home; and the value of open-ended activities that encourage creativity and self-direction over rigid instructions [18].

Another layer of engagement comes from the way information is presented. As Marcus and Kowitt [20] argue, students benefit from understanding not just the "what" of exhibits, but the "why" behind them. Their recommendation to use exhibit “footnotes” mirrors how academic texts explain their sources—helping young visitors better grasp the narratives and interpretations behind what they see.

Together, these studies and strategies provide a strong foundation for designing museum exhibits that are engaging, equitable, and educational. The exhibit developed in this project draws heavily on these insights, ensuring that every design decision is rooted in best practices and proven methods for maximizing learning and enjoyment.

2.1 PERSONAL CONTRIBUTIONS

At the early stages of our project, I helped guide the team toward a more focused interest in sustainable energy. While there was a general enthusiasm for environmentally conscious topics among the group, my research specifically explored clean energy systems, including smart grids, solar energy optimization, and AI-driven forecasting models. Sources such as Wang and Leng’s review on integrating wind energy into smart grids [21], Hu et al.’s work on how smart grids support energy sustainability [22], and more recent studies on solar power optimization through AI [23], [24] deepened our understanding of real-world solutions for a low-carbon future. These findings were critical in helping our team prioritize a sustainability topic that was not only relevant and impactful but also translatable for a younger audience.

When it came time to choose our final topic, I supported the decision to focus on biogas as a sustainable energy source. Given my background research and our shared goal of making the exhibit educational and child-friendly, biogas stood out as a digestible (and hands-on) concept that could be broken down in a fun and visual way. It offered a balance between technical relevance and accessibility—connecting ideas like food waste and decomposition with energy creation in a way that children could grasp and get excited about.

In addition to research, I contributed to the ethical considerations and inclusive design of the exhibit. Drawing from my understanding of museum engagement strategies, I proposed that our exhibit include slanted walls and interactive features to increase visual appeal and physical accessibility. This suggestion was based on my observations during our visit to the Museum of Science in Boston, where I noticed how slanted and lower-positioned interactive elements made exhibits more engaging for younger visitors and more inclusive for children of different heights and abilities. This design choice also aligned with what we learned about accessibility-focused exhibits—such as those with large buttons, angled touch screens, and tactile engagement features—which I emphasized during team discussions.

Finally, I played a large role in shaping the problem statement, ensuring that it reflected not only the importance of teaching sustainability, but also the need for equitable and engaging learning experiences. My input helped ground the project in both research and ethical design principles, making sure our solution didn't just inform—it invited participation from all individuals.

3 METHODOLOGY

3.1 PROBLEM DEFINITION

To define our problem, we first recognized the need for a more engaging way to introduce children to sustainable energy. During visits to Beachmont Elementary School, we asked students about topics and exhibit features that interested them. Their feedback guided us toward themes that felt relatable and interactive—things they encounter in daily life and enjoy learning about through hands-on activities.

From there, we explored different sustainability topics and ultimately chose biogas. This theme allowed us to connect food waste, something familiar to students, to clean energy. It offered a clear and visual process we could simplify into an exhibit that was easy to follow and exciting to explore.

We also studied museum exhibit design strategies, focusing on how layout, movement, and visuals can support learning. Developing an enclosed up-front design, we considered adding slanted walls and unique features to make the exhibit feel more immersive and less like a traditional display.

By combining direct input from students with design research, we formed our guiding question: How can we create an interactive exhibit that helps children understand biogas and its role in sustainability in a way that feels exciting and approachable?

3.2 SOLUTION GENERATION

Our solution generation process began with a team-wide brainstorming session centered around sustainability, specifically renewable energy. Each member brought in ideas backed by personal research, and together we explored a wide range of potential topics—from solar and wind energy to composting and waste reduction. To expand the solution space, we encouraged open discussion without initially filtering ideas, allowing us to generate a variety of directions before narrowing them down.

Through this process, we noticed that topics with clear, simple processes and everyday relevance resonated most. Ideas that involved familiar settings, like farms, or involved humorous or gross-out elements—such as gas or waste—sparked the most excitement. These aspects felt accessible to children and could be presented in a light-hearted yet educational way. I personally emphasized the importance of relatability and simplicity based on our early conversations with students, helping steer us toward concepts that would be easier to visualize and explain.

We collectively leaned into the farm-to-energy concept, eventually landing on biogas as our focus. Its process—from food waste to fuel—is straightforward and offered plenty of room for interactive, hands-on exhibit features. The humor and novelty of turning waste into energy gave us a fun entry point for serious topics.

Overall, our team prioritized solutions that were both educational and memorable, using the students' interests and feedback as a compass throughout the process.

3.3 DECIDING ON A SOLUTION

To determine the final subject for our exhibit, our team conducted a Kepner-Tregoe Decision Analysis (KTDA) using four main criteria: interactivity, appeal to children, educational value, and ease of production. These categories were chosen to reflect our goals of creating an engaging, accessible, and informative exhibit that could realistically be built within our timeline and resources.

Our candidate topics included biogas, solar smart grids, solid-state batteries, and carbon capture. We rated each topic against the criteria on a numerical scale, then assigned weights to each criterion based on its importance. For example, appeal and interactivity were weighted slightly more heavily since they were crucial to keeping children engaged, while educational value and production feasibility were also significant in shaping the practicality of our final product.

Biogas emerged as the top-ranked topic. It scored highly in interactivity due to the potential for visual and physical components, such as animated gas production or waste-to-energy transformations. It was also considered more appealing to children because of the playful nature of farm-related themes and the humor associated with waste and gas. Educationally, it allowed us to clearly illustrate a renewable energy cycle in a way that was tangible and easy to understand. Lastly, from a production standpoint, biogas was more feasible to prototype compared to advanced technologies like solid-state batteries or large-scale solar grids.

The KTDA (Appendix D) helped us make a well-rounded decision that balanced creativity, clarity, and deliverability. Biogas offered a strong intersection of all the factors we valued, making it the most suitable choice for our exhibit's focus.

3.4 IMPLEMENTATION

Our implementation process followed a structured and iterative workflow that emphasized collaboration, technical testing, and precise fabrication.

We began by dividing construction responsibilities among the team based on individual strengths. Roles were assigned across five major areas: aesthetics and educational infographics, base structure, gas chamber panel, monitor panel, and the interactive game system. This division allowed parallel development while ensuring that each component supported the overall design vision.

Once roles were set, we transitioned from concept sketches to CAD modeling. We used Solidworks to create individual parts and assemble them into a cohesive 3D model. This phase was critical in helping us visualize the scale and layout of the exhibit, taking into account real-world constraints like transportability, user accessibility, and overall footprint. During this stage, we uncovered and resolved several overlooked design issues, such as spacing for electronic components and cable management.

To move toward physical construction, we reformatted our CAD components into AutoCAD to create precise 2D vector drawings for laser cutting our wooden parts. This required close attention to material thickness, slot fit tolerances, and structural stability to ensure a seamless assembly during fabrication.

In parallel, we developed a flowchart to guide the game system logic and overall user walkthrough. The exhibit includes two primary activities: a waste sorting game and a biogas temperature challenge, both designed to combine learning with hands-on engagement.

We built a cardboard prototype to test the spatial configuration, user interaction, and placement of visual elements. This step helped us verify the ergonomics and allowed quick adjustments before committing to final materials.

From a technical perspective, we created proof-of-concept builds to test our servos, game logic, and user interaction through the SparkFun hardware. To support the exhibit's monitor display, we developed serial communication between Arduino and MATLAB, allowing the program to send data to MATLAB for real-time feedback on the screen. This step added a dynamic, responsive layer to the exhibit and helped simplify user instructions.

By following this phased development—starting with delegation and CAD, advancing through laser-cut fabrication, logical design, physical prototyping, and hardware integration—we ensured a professional, thoughtful implementation of our final exhibit.

3.5 EVALUATION

Our evaluation strategy focused on three key areas: user engagement, enjoyment, and knowledge retention. We planned structured methods to collect and analyze data from student interactions with our exhibit.

Engagement Time:

To measure interest, a team member timed each user's interaction using a stopwatch, starting when they engaged with the exhibit and stopping when they left. We aimed for a median engagement time of 1.75 minutes, with at least 75% of users staying for more than 1 minute. A histogram was planned to visualize this data.

Enjoyment Rating:

Students were asked to evaluate their enjoyment of the exhibit following the interaction. This metric helped us understand the appeal of the exhibit compared to others, and a bar chart would be used to present the distribution of responses.

Concepts Learned:

To assess learning, we tracked game win rates and collection statistics. These variables served as indicators of learning and retention.

These evaluations allowed us to assess both the effectiveness and appeal of our exhibit, informing further improvements.

3.6 INDIVIDUAL CONTRIBUTIONS

Initial Design Ideation & CAD Development

In the early stages of our design cycle, I contributed to shaping the physical layout of our exhibit by proposing the slanted field design. This approach helped create a more immersive and visually engaging experience for students. I then CAD-modeled the main base panel, which housed critical components including electronics, user interface buttons, and our tractor mechanism. Throughout this process, I evaluated design constraints related to transportability and component accessibility, using feedback from our initial sketches and CAD assembly to revise dimensions and layout.

Tractor Mechanism & Baseplate Integration

A major contribution was the design of the interactive tractor mechanism central to our biogas farm narrative. I engineered a servo-based system where a rod-guided tractor would move across the slanted field. This required precise elevation of the baseplate to ensure clearance for underlying electronics. I prototyped this using cardboard models and refined it through 3D printed iterations. These efforts helped bridge the technical functionality with a narrative that kids could follow and enjoy.

Biogas Temperature Game Design

I also led the design and programming of the two-player biogas temperature game. In this activity, one student controls a crank (rotary encoder) to generate biogas, while another adjusts a temperature dial to stay within an optimal range. I wrote the Arduino code, developed the proof of concept for the rotary encoder, and calibrated the servo-controlled dial to ensure an engaging and challenging gameplay. This game was then translated to be MATLAB-compatible using serial communication, allowing it to interface with our display monitor and enhance visual feedback.

3D Printing & Hardware Coordination

Beyond CAD, I managed all of our 3D printed components, including the tractor model and mechanical parts of the servo system. I optimized prints for fit and durability, adjusting tolerances based on print failures and user testing data.

JOSEPH AFFLITTO

4 INTRODUCTION

To enhance educational accessibility for young students and promote awareness of sustainability, we developed an engaging, hands-on game that guides users through the biogas production process.
The interactive design encourages learning through trial and error, helping students absorb information more effectively and retain it over time. By actively participating in the process, users are more likely to connect with the material in a meaningful way. The game simplifies complex concepts into digestible steps, making sustainability education both approachable and enjoyable.

4.1 PROBLEM STATEMENT

The process of researching, developing, and creating a fully functional exhibit has allowed the team to come to a deep understanding of the problem at hand. Sustainability isn't being taught to elementary and middle schoolers with enough emphasis on engagement and long-term retention. Climate change is occurring at a rapid rate, and its effects will permeate across all of us and future generations. Current methods of education, however, are often restricted to classroom settings, which can be difficult for engagement and hands-on learning opportunities. The students need a method to learn in an environment where they can explore in a creativity and free way, while still having access to accurate and credible information.

Through various research and studies, we found that young students often find the most growth in knowledge through trial and error, being allowed to fail initially and using that failure to fuel future success [17]. As such, we designed a game system that allows users to learn through efforts and improvements, as opposed to standardized information and questions.

We found biogas to be a compelling topic as it introduces users to unfamiliar real-world scenarios while incorporating light-hearted elements like potty humor to capture their attention. This playful approach helps break down barriers to engagement, making scientific content more approachable and memorable for younger audiences.

Our approach will motivate students by turning learning into an interactive experience that requires them to master the material to succeed. The exhibit will be designed to be welcoming and encourage teamwork, making it easy for students to collaborate. The task will be structured so that achieving success relies on a solid understanding of the concepts presented. This activity will last only two to three minutes and will be compact and easy to move. It will be designed within a strict budget of one hundred dollars, with constraints based on our technical expertise and capabilities.

4.2 STAKEHOLDERS

Our design was manufactured with the intention of users being youths of elementary and intermediate school age (9-14 years old). These students are at an interesting point in their academic careers, where they've begun to develop affinities and interests but are still limited to early school standards and processes for learning. Their exposure and development alongside technology has drastically changed the way they intake information. The schools where we plan to implement our design serve communities with a high population of immigrant students, who may have had limited exposure to STEM fields and opportunities. We hope our design can serve as a spark for interest in STEM and sustainability practices going forward.

Sustainability topics, like Biogas, are particularly relevant to this generation as they have grown up in a world clouded by the pertinent effects of the Climate Crisis. This issue will continue to be one of the biggest threats to human life throughout their generation. Assuring they are educated and knowledgeable on the problem and potential solutions gives them the abilities to contribute to the efforts of protecting our home.

Beachmont Veterans Memorial School and Garfield Middle School are the clients for our design project. They will receive an educational pop-up museum aimed at engaging students in STEM topics. These schools currently have limited resources to provide students with learning experiences beyond the standard curriculum. They see this project as an opportunity to expand students' exposure to STEM and offer more diverse learning opportunities.

Parents and teachers of the students should also be considered secondary beneficiaries of the design, as they value both student enjoyment and educational enrichment. They will expect the designs to offer a fun environment that stills prioritizes learning from interaction.

4.3 REQUIREMENTS

Several physical restrictions were worked around when planning and implementing the final design.

The first, most prioritized requirement was assuring the safety of users. The design prevented sharp corners, exposed wiring, heavy objects, and secured large pieces in an effort to minimize risk of injury.

The design also needed to be easily transportable without risk of damage. To meet this requirement, it had to be lightweight enough for a single team member to carry over the necessary distance. Additionally, it needed to be quickly reassembled—ideally in under 15 minutes.

The entire project had to be restricted to a $100 budget, which covers the cost of any items purchased specifically for the purpose of this project.

Non-physical requirements included an emphasis on educational value and long-term retention. Based on our research, we implemented various pedagogical techniques to increase learning and retention [16]. These techniques included productive failure and interactive education, allowing students to actively work towards tasks and learning through their efforts and failures.

4.4 ETHICAL CONSIDERATIONS

Our design is directly interacted with by the students so it was essential to prioritize safety, inclusion, and accessibility. We adopted a Value Sensitive Design approach to ensure that user values and ethical considerations were embedded throughout the design process.

Accessibility and inclusion are crucial to the success of the design goals as laid out in the problem statement. Students of all circumstance and standing need an equal opportunity to be exposed to the exhibit. We ensured that individuals of all abilities could fully interact with the exhibit. This influenced layout, component height, and user interaction space.

Safety was especially important given our primary users are young children. Design elements and materials were chosen to eliminate sharp edges and heavy or unstable components, minimizing potential hazards during interaction.

Recognizing that children engage more through hands-on experiences than passive learning, we incorporated elements that promote play, exploration, and sensory involvement.

By centering our design around VSD principles, we created a solution that meets functional goals while remaining ethically and socially responsible.

4.5 BIOGAS

The core sustainability topic of our exhibit is the creation and use of biogas as a source of alternative fuel for the future. Biogas is a type of renewable energy that is produced through the breakdown of organic matter by microorganisms in the absence of oxygen, known as anaerobic digestion. The exhibit simplifies this process to three main facets: Collection, Conversion, and Use.

The production of biogas also offers significant environmental benefits, as it helps to reduce greenhouse gas emissions. By capturing and utilizing methane—a potent greenhouse gas—biogas provides a cleaner alternative to traditional fuels like gasoline, burning much more efficiently and with fewer pollutants. Giving students a detailed understanding of alternative energies of the future helps them familiarize with new technologies, reducing reliance on and support for harmful fossil fuels. I This knowledge can inspire curiosity and generate interest in renewable energy technology that motivates them in the future [1].

4.6 SCOPE

The report will address the engineering design process that went into the development of the final exhibit. It will detail the priorities, errors, obstacles, and considerations addressed through the process.

It will also serve as an analysis and reflection on the effectiveness of the implementation, assessing the success of retention, engagement, and enjoyment from the design.

5 BACKGROUND

Our biogas museum exhibit was shaped by insights gathered from service-learning experiences and studies in sustainability. We recognized the need to engage young learners in environmental education and developed an interactive exhibit to simplify the concept of biogas technology. By integrating effective museum design and elements of gamification, we aim to make learning about renewable energy both accessible and enjoyable, sparking curiosity and encouraging environmental awareness. This section outlines the research and guiding principles that influenced the design of the exhibit.

5.1 RESEARCH AND CONSIDERATIONS

Our research initially stemmed from qualitative observations made during service-learning experiences and interactions. Understanding the behavioral trends of this age demographic helped us better understand their interests and learning styles, making it easier to cater an exhibit to them. These experiences are largely influential toward the development of the empathy map, seen in Appendix B.

We recognized that teaching styles and prioritizing entertainment to improve engagement are very beneficial to student learning, which are both elements we plan to design our museum exhibit around.

With a short visit to the Museum of Science, we were able to understand how other projects addressed shared goals. Exhibits used buttons, wheels, and other interactive pieces that kids could touch and play with. These elements were very effective in engaging students and hooking them into a game, before introducing the learning elements of the design. It also became apparent that using familiar iconography and ideas can help children feel more comfortable interacting with an exhibit.

Designing an exhibit that accommodates at least three students at a time, while also providing space for others to observe and preview the activity, can significantly enhance engagement. Effective museum experiences for adolescents should address three key cognitive stages: intake, processing, and storage of information.

Adolescents are most receptive to new information when it is presented through sensory engagement, piques their curiosity, and feels relevant to their everyday lives. This can be achieved using touch screens, interactive models, bold visuals, immersive audio, and modern cultural references to create a sense of excitement and familiarity [15].

The processing stage—where deeper learning occurs—is best supported through interactive elements like simulations, gamified experiences, and cause-and-effect demonstrations, which shift learning from passive observation to active participation [15] .

For lasting retention, exhibits should foster social interaction and offer take-home components, helping to solidify the learning experience and extend its impact beyond the museum visit.

We used this information to guide the search of potential sustainability topics, which would then be adapting into a final design exhibit idea.

5.2 PERSONAL CONTRIBUTIONS

Through the initial phases of development, I found myself committed to prioritizing an enjoyable, fun exhibit idea that can give users a positive experience overall. When shaping the problem statement, I felt it was important to make student enjoyment a primary goal—placing it above other objectives—to spark their interest in STEM and encourage continued curiosity in the subject. These concerns guided my research towards understanding what educational techniques could optimize this result.

Extensive research has been dedicated to the pedagogical techniques that can be used to improve entertainment while retaining the educational value of the endeavor. One of the most notable efforts was the strategy of gamifying learning, incentivizing learning through direct input and action [17]. Further research indicated a productive failure-based learning style, one which encourages students to learn by making mistakes and trying again, works especially well at increasing learning and retention. This style of learning seemed to connect very directly to the gamifying of learning, with the hands-on style of gameplay lends well to providing students with freedom of trial and error.

With these guiding principles of education set, I searched for a sustainability topic which offered a good opportunity to realize them. After coming across biogas technology, I found the relatively simple and visual process to be a strong candidate for the leading topic of the exhibit.

My efforts in grounding the exhibit in proven educational strategies like gamification and productive failure, and pairing these with an engaging, hands-on topic like biogas technology, assured the design process remained focused on creating an experience that is both enjoyable and educational. This foundation ensures that the final exhibit not only captures students' attention but also fosters meaningful, lasting engagement with STEM concepts.

6 METHODOLOGY

This section will briefly detail the necessary steps, iterations, and methods used to approach the problem and develop a capable solution through our final exhibit design.

6.1 PROBLEM DEFINITION

To fully understand and define the problem, we began by conducting extensive research on the challenges surrounding sustainability education for children. We focused on identifying the gaps in how sustainability is currently taught and how we could address these gaps in a more engaging and accessible way.

First, we explored existing educational methods for teaching sustainability to children. This included reviewing current curricula, identifying trends in teaching styles, and observing how sustainability concepts were presented in both formal and informal learning environments, such as museums. We found that sustainability topics were often presented in an information-heavy manner, which could overwhelm young learners and limit their engagement.

We also researched best practices in museum exhibit design, particularly for children, to understand how to create an environment that fosters curiosity and hands-on learning. We investigated successful examples of interactive exhibits and analyzed how these exhibits captured children's attention while educating them on complex topics. Additionally, we reviewed research on inclusive design practices, ensuring that our exhibit would be accessible and engaging for all children, regardless of their background or abilities.

To deepen our understanding of the problem, we incorporated insights from service-learning experiences at Beachmont Elementary School. By working directly with children, we gathered feedback on how they engaged with various learning activities. This helped us identify key elements that contribute to successful engagement, such as interactivity, visual aids, and a space that feels personal and inviting.

By combining research on current sustainability education, best practices in exhibit design, and insights from real-world interactions with children, we were able to define the problem and set clear objectives for our project. Our goal was to create an exhibit that would simplify sustainability concepts, making them accessible, engaging, and fun for young learners while promoting a deeper understanding of environmental responsibility.

6.2 SOLUTION GENERATION

The solution generation process started with a simple, brainstorming session. This session allowed us to find sustainability topics that could be interesting ideas for the exhibit. Each member was assigned a topic to research further.

With a developed information background on these topics, we engaged in a second group brainstorming section. Each idea was developed as a potential standalone exhibit that could educate children while encouraging hands-on engagement. This approach allowed us to explore a wide range of concepts, ensuring that we selected the most engaging and educational topic for young learners.

After an extensive period of brainstorming, we used storyboarding as a method of organizing the conceptual ideas into specific, feasible designs. These sketches are visible in Appendix C.

Through this iterative process of brainstorming and evaluating different ideas, we expanded our solution space and ensured that our final exhibit would be both creative and educational.

6.3 DECIDING ON A SOLUTION

With a detailed solution space having been explored, we used a Kepner-Tregoe Decision Analysis to decide on a final design idea to continue with. We focused on four main criteria: interactivity, appeal, educational value, and production feasibility. These criteria guided our decision-making process and were essential in narrowing down our final concept. We prioritized interactivity by incorporating hands-on elements. To ensure the exhibit was appealing, we designed it with a colorful, open trifold structure. Educational value was emphasized by explaining the processes in simple terms, helping children understand the topic in a detailed, but clear way. Finally, we considered production feasibility, ensuring the design could be realistically created within budget and time constraints. Each concept was rating based on these criteria, and the biogas exhibit ultimately scored the highest, making it the most viable choice for our project.

6.4 IMPLEMENTATION

Throughout the design phases, the prototype evolved significantly in response to functional goals, mentor feedback, and user testing. Initial stages focused on core mechanical and electronic components, particularly the servo motor systems, which were essential for interactive gameplay. These motors were integrated into mechanisms that translated rotational motion into linear motion for the waste basket game and tractor movement. Early proof-of-concept testing confirmed the feasibility of these elements, leading to their formal inclusion in the final design.

The first prototype helped define the layout and structure of the exhibit. A modular panel system was adopted to organize and house the exhibit's key features. The base panel was designed to accommodate electronics and wiring, while the middle panel supported a monitor and LED displays essential for visual feedback and game interaction. A third component, a tri-fold information panel, was designed and printed to deliver educational content and enhance thematic cohesion.

Design choices were continuously refined in response to structured evaluation metrics and feedback. Testing showed that while core mechanics performed well, issues with button clarity and LED signaling occasionally hindered user understanding. These observations informed later revisions, including plans for improved lighting, clearer instructions, and enhanced graphical content on the monitor. Also, through peer-reviews we found some of the text-heavy elements were critiqued for unnecessary information and lack of clarity. Moving through the final design, we integrated video instructions to streamline information and gameplay elements with a more visual display.

The durability of the exhibit became an apparent issue as transport began to cause multiple structural issues. The design also struggled to function as a free-standing structure. To address both of these concerns, additional supports and protective elements were added to the panels and the base. The final design combines the previous iterations and developments into a final product that offers a compromise for the many considerations previously mentioned to form a successful final exhibit.

6.5 EVALUATION

To effectively evaluate the success of our exhibit, we will implement a structured assessment strategy based on three core metrics: time spent at the exhibit, visitor enjoyment, and concept retention. Each metric will be measured using a distinct method tailored to capture meaningful engagement data. The duration of each student's visit will be tracked using a timer, with a target of at least 75% of users remaining for over one minute—indicating sustained interest and active participation.

Upon completing the exhibit, visitors will be encouraged to answer a brief set of questions on the biogas process and rate their overall experience. As an incentive, a small prize will be offered upon completion.

To assess concept retention, user interaction data will be collected directly from the games. In the first game, the number of buckets successfully filled will serve as an indirect measure of understanding waste categorization and properties. In the second game, success rates will reflect the user's grasp of the necessary conditions for biogas conversion. Together, these tools provide a comprehensive evaluation framework that balances engagement, satisfaction, and educational impact.

6.6 INDIVIDUAL CONTRIBUTIONS

During prototype and final product design process, I took a lot of steps towards designing the physical hardware of the exhibit. This extended to encompass the panel designs, the supports, the implementation of various mechanisms, and the placement and cohesion of the various game components. While other group members focused on more specialized aspects of the design, my efforts helped bring the multiple sections of the design together and make everything flow seamlessly.

In the early stages, I focused on designing the overall form factor of the panels, ensuring that they were structurally sound, modular, and capable of supporting the various interactive components we envisioned. This included careful planning of dimensions, alignment, and access points for future wiring and motor integration.

As we transitioned into the final design phase, I reinforced these panel structures and was responsible for incorporating finalized elements from my teammates, integrating their specialized contributions into the exhibit in a way that felt unified and coherent. I also designed the tubing paths, which serve both functional and aesthetic purposes, as well as the housing structures for the atomizer, crank mechanism, and LED strips.

I used AutoCAD extensively to model each component of the exhibit, and I managed the laser cutting process for all custom pieces, ensuring accuracy and consistency across the board.

In addition to my technical responsibilities, I played an important role in guiding the overall creative direction of the project. As each team member brought in their own ideas and elements, I helped facilitate conversations and decisions that tied everything together, ensuring that our exhibit wasn't just a collection of individual parts, but a cohesive, engaging experience. This combination of hands-on building, digital design, and team coordination was key to bringing our vision to life.

The experience with the project mentors offered an unique opportunity to learn from someone who had already gone through the process of design and could sympathize with the struggles and difficulties we would undoubtedly face. These conversations served as a way to have our troubles venerated, providing confidence and assurance that we could overcome. From a more technical standpoint, the mentor's input helped us maintain a commitment to an interesting and exciting project while managing a reasonable workload and level of expectations.

EVA MESCHER

7 INTRODUCTION

This report introduces and covers our design regarding a sustainable museum exhibit for children of elementary and middle school age focused on the topic of Biogas.

7.1 PROBLEM STATEMENT

The problem is that sustainability isn't being taught to elementary and middle schoolers with the goal of engagement and long-term retention. This is important because climate change is happening far faster than we originally anticipated and it will certainly affect all of us and future generations. Current methods of education, however, teach students about sustainability in a classroom setting which doesn't necessarily engage all students, and might not spark their interest in the subject in the long run. The students need an opportunity to learn in an environment where they can explore and learn about topics they find interesting.

Our solution will engage students through the gamification of learning and will challenge them to learn the material to achieve success. We focused on including countless interactive elements to challenge the students and promote their learning and growth around our topic of Biogas. To engage students, we created a fun and lighthearted atmosphere utilizing bathroom humor to engage the kids. A focus on accessibility was also emphasized to ensure participation from all students as well as a collaborative space where students can work together. This solution will provide the students with a challenge that can only be completed well and successfully if they understand the concepts we have presented them with. This learning experience will be limited to two to three minutes and will be easily transportable and within the size constraints. The exhibit must be able to fit on a 36" wide by 28" deep tabletop. It must also be transported in a bag of size 27.6" by 13.8" by 16.5". Further the costs must be under a budget of $100.

7.2 STAKEHOLDERS

Our design is targeted at an audience of younger students. Our primary users are elementary and middle schoolers aged from around 9 to 14 years old. These students are towards the beginning of their academic careers and are likely still figuring out what interests them in school. They have also grown up in the digital age and many are deeply integrated into the online gaming world. They likely don't have the longest attention spans and might find certain aspects of school boring. However, they have also grown up in a time where climate change and global warning are becoming increasingly pertinent to our lives. These students will be affected by this at some point in their life if they haven't already been. They are also one of the generations who this burden will befall upon. It is important they are educated on these topics so that they can contribute to this issue and protect our earth. Many of these students also come from immigrant families who some might not have a large background in science or any STEAM related fields. Exposing these kids to these ideas and fields and hopefully sparking their interest is one of our main goals. Our design is mainly aimed at creating an experience for these kids that they enjoy and contribute to sparking their interest in a topic of sustainability.

Our clients are the Beachmont and Garfield schools. They are expecting us to create a fun and educational pop-up museum for their students. These schools are in lowincome areas and might not have all the resources they need or would like. Many of their students might not have the opportunity to go to the science museum, so they are expecting us to create a pop-up museum so their students can participate in this experience.

The main secondary beneficiaries are the parents and teachers of these students. They are expecting our designs to be age appropriate and create a fun learning environment for their children. Engaging their children, capturing their attention, and teaching them something new is something parents and teachers care deeply about.

Finally, we as designers are secondary beneficiaries. This project has helped us learn and grow as engineers. We have learned how to create real-world products and solutions through the engineering design framework. This project has provided us with the opportunity to create and improve our skills which will help us in the long run.

7.3 REQUIREMENTS

The main requirements for this project concern the safety and transportability of the exhibit. Our users are children, which means our exhibit must be safe for them to use. This means there cannot be any sharp edges, heavy objects, exposed wires, etc. It must be able to be safely transported to and from the children's school without getting damaged. This also requires that the exhibit can be easily carried by fewer than two people and can be set up within 15 minutes.

The design must include at least two unique interactive Arduino-based elements for the user. Our design utilizes buttons, servo motors, an encoder, as well as LED strips. We chose these elements because we felt they allowed for a truly interactive experience for the kids. The design must also contain at least one 3d printed or laser cut part.

Finally, there is a budget of $100 dollars. This does not include any items previously owned, only those purchased for this project.

7.4 ETHICAL CONSIDERATIONS

Our design affects real people, children, parents, teachers, friends, etc. It is important that the design is safe, inclusive, and accessible to all these people. This is why creating a Value Sensitive design is so important. A value-sensitive design is on in which the values and needs of the target audience are considered. Using this method ensures that these ethical principles are integrated into the project.

We focused on accessibility, inclusion, safety, and interactivity. Accessibility and inclusion were two of our main focuses when updating our problem statement. We wanted to ensure that all people were able to interact with our exhibit if they chose to do so. We wanted to ensure that if a child or adult were in a wheelchair for example, they would be able to reach all of the necessary components and be able to see everything. This affected many parts of our methodology and design process as we brainstormed ways in which to achieve these goals.

We also considered the need for a safe exhibit. Young children especially like to touch everything and play with it, this is why making sure that there are no sharp objects or objects that are too heavy to lift is so important. We realize that our main users are younger children, so we ensured that our design fit their needs over those of an adult.

Finally, we prioritized creating an interactive exhibit. Children, as mentioned previously, don't always have the longest attention span and they likely will get bored partaking in passive learning like reading or watching a video. They like to play and use their senses to interact.

Creating an exhibit geared at these aspects was a big part of our consideration, especially in our methodology.

7.5 BIOGAS

The topic we ended up choosing for our exhibit was Biogas. This is a renewable energy source that is produced from the breakdown of organic waste. It is sustainable and renewable unlike other sources like natural gas which rely on fossil fuels. Biogas uses anaerobic digestion from anerobic bacteria that break down organic waste and convert it into primarily methane gas and carbon dioxide. This gas can be used as a heat source for homes or it can be used in a combustion engine to produce electricity [1]. This process reduces the amount of greenhouse gases in the atmosphere. Biogas collects these gases and uses them to produce energy. It burns far cleaner than gasoline and has the potential to greatly reduce emissions [2]. This alternative can be very useful in a more rural area in a farm-like setting or in a city where waste and trash is stored.

7.6 SCOPE

This report focuses on the problem and the design process implemented to work towards a prototype of a solution. The methodology used includes the problem definition, solution generation, decision making process, implementation, and the evaluation stages. This report will cover all these aspects and show our proposed solution and prototype. This includes our code, CAD drawings, physical mockups, and our final prototype itself.

8 BACKGROUND

Engaging children in learning through schooling is the common practice for educating individuals. The question is how you make this fun and engaging for the students so that they enjoy it and want to keep learning. One solution outside of school is museums. After visiting the Museum of Science in Boston, we were able to see and experience how they made learning so fun and interactive. There were many different general tactics that they used throughout most of the exhibits. Many of the exhibits included buttons and moving parts. They had real-life model figures rather than just images on a screen. When walking around the museum I noticed that often kids would just go up to exhibits to hit the buttons and play with the different parts. They like interacting with exhibits by moving and touching everything rather than solely reading and listening. These are ideas that we kept coming back to in our own design.

There was also another commonality among the exhibits. They all had accessibility in mind. Many of the exhibits with interactive screens were low to the ground and angled at around 15 degrees rather than flat or vertical. The buttons or pieces of physical interaction were large and easy to press. When designing we tried to implement these ideas to ensure that our whole exhibit was accessible to all. To ensure our design was value sensitive and ethical we also conducted some research into inclusive designs and the learning process. Often girls specifically, are overlooked and many designs end up being geared more towards boys which results in lopsided interaction data.

The Exhibit Design for Girl's Engagement (EDGE) has three main design attributes. The first is the labeling of the exhibit. Using labels to show the kids how to play is important, however certain aspects of these labels can make a difference. Having labels that are visual to convey meaning, are far more important than written instruction. Including labels with pictures of people is important to give context to the exhibit and make it relatable to the kids [3].

The second design attribute is focused on the look and feel of the space. Including familiar objects is important to helping the kids relate to the exhibit and feel more comfortable participating in the activity. Creating a homey, personal, and playful feel to the space is also important to helping the kids feel more invited and included to participate [3].

The final design attribute is focused on exhibit interaction and how to make it feel more inclusive. Having multiple stations or sides to an exhibit can give kids a space to work independently or collaborate with their peers if they choose. Having an open design is important because it not only gives kids the opportunity to work together, but it also allows others to preview and watch their peers play before they go. This is something that was found to be important, especially for girls, in creating a comfortable environment. After watching others play, children are more likely to participate because they have gained confidence through previewing the activity. It is also important that the activity is more open-ended and there are not a set of predetermined steps one has to take to succeed or accomplish the goal. The kids can make their own choices and see how that affects the outcomes [3].

Creating a design that follows many of these principles is the key to creating a fun and interactive exhibit where the kids want to learn and enjoy learning. These ideas and design attributes help motivate kids to participate and try their best at an activity and hopefully in the end learn something new.

8.1 PERSONAL CONTRIBUTIONS

I focused my research on attributes of an inclusive design as well as sustainability topics that might fit the problem. I started my research on how to make an inclusive exhibit. As the group worked towards creating our problem statement, I helped ensure that aspects of these were included and integrated into the statement. I also did some research into the different stages of learning and how this might affect our design. I tried to take advantage of our Museum of Science exhibit and stayed after to explore more of the museum. This really helped me learn and see the different techniques being used as well as the commonalities among the exhibits. These ideas proved to be very helpful when considering different ways in which to make our exhibit engaging and fun for the kids. Seeing these designs also highlighted the ethical considerations needed to be made. As mentioned earlier it was clear that many of these exhibits were aimed at being accessible to everyone and being inclusive to everyone. This is something that we integrated into our thinking and our problem statement.

I also focused my research on possible sustainability topics that might fit this problem well. I researched many different new and unique sustainability ideas that were being implemented throughout the world as well as those being developed. I ended up focusing my research on two of these ideas. The first was the desalination of saltwater through the process of reverse osmosis. This could help provide freshwater access to those living in remote areas. As freshwater access becomes scarcer the demand for this type of technology grows.

The second topic I focused on was the development of solid-state batteries. Solid state batteries differ from traditional lithium batteries because they don't have a liquid component which is flammable. These solid-state batteries have a greater energy density, longer lifespan and faster charging times. They are safer (have lower chance of overheating) and they can be made even smaller and lighter than traditional batteries. More importantly, they use fewer materials that are less harmful and more accessible (like salt) than traditional lithium-ion batteries. While neither of these topics ended up being chosen, they still helped contribute to the generation of a full solution space.

9 METHODOLOGY

9.1 PROBLEM DEFINITION

To fully understand and define the problem each group member conducted individual research. The two main focuses on this research were the attributes to creating an engaging museum design as well as potential sustainability topics.

Before conducting this research an empathy map, which can be seen in appendix B, was created to be able to empathize with our audience and create an exhibit geared towards them. We considered our main audience to be children in elementary and middle school. This map outlined who our audience was, what they see, hear, feel, think, say, and do. This exercise helped us try and get into the minds of our audience and helped us better define the problem.

From here individual research was done focusing on how to create an engaging design and possible topics. Each group member came with information from at least two different sources on how to make an inclusive exhibit. This information was synthesized and integrated into our problem definition. We constructed our problem statement after conducting this research and laying out the goals, constraints, and functions of our exhibit. Each group member also focused on at least two different sustainability topics that could potentially be used. Having all these initial ideas helped us not only further define our problem but also generate solutions.

9.2 SOLUTION GENERATION

For the next step of the design process, generating solutions, we took the initial ideas we researched in step one and narrowed them down to four ideas through discussion. We discussed which ideas were the most relevant to our audience, which ones fit the project description the best, and which ones got strong feedback from the townhall presentation.

To generate solutions or possible exhibit ideas from these, we did a group brainstorm. For each topic we threw out ideas building on each other and not constricting ourselves to one idea. Some of the solutions overlapped with each other between topics. This brainstorm was so successful because every group member participated and tried to think of ideas for each topic, not just the one they had originally researched. This helped us create a full solution space with multiple ideas, any of which could be successful.

Each of these solution ideas consisted of many different parts or ideas, but they lacked a cohesive narrative. To create this, we used the technique of storyboarding. We discussed possible narratives and outlined a loose sequence of steps. This helped us storyboard and create sketches that showed the idea and narrative. This can be seen in appendix C.

9.3 DECIDING ON A SOLUTION

To decide on a solution, we utilized a Kepner Tregoe Decision Analysis chart. We chose our main objectives and split them into four major categories: interactive, appeal, education, and production. We prioritized interactivity and the incorporation of physical, hands-on elements. We also prioritized the visual appeal which included elements that were colorful, engaging, inclusive, and relatable to them. For the last two categories we wanted to ensure that our design was sustainability-focused and something the kids could understand. It was also important that it was something we could reasonably design and produce. We weighed each of these categories along with their respective subcategories. We valued the appeal the most followed by interactivity, educational value, and finally production feasibility. Each solution was scored for each category and our final decision, Biogas, won by a margin of greater than 10%. This process can be seen in appendix D.

9.4 IMPLEMENTATION

To implement our solution idea, we started out by discussing all of the possible paths we could take. We followed our general outline decided earlier, but to figure out the specifics we went back to step two and generated even more ideas. We discussed how our layout would look and decided a trifold design would be the most value sensitive and inclusive. This helped us narrow down some of our ideas and start creating CAD sketches and a flow chart. Each group member created a drawing of a possible layout and then we discussed the pros and cons of each. We ended up deciding on a layout that incorporated many of these design ideas. CAD drawings, which can be seen in appendix E, were then created which helped in constructing our first cardboard mock-up.

After this we started designing our AutoCAD sketches to laser cut the wood and replace the cardboard mock-up. After receiving feedback from our townhall meeting we made some adjustments to our design and proceeded to start cutting and building. We also focused on creating proofs of concept for different components of our game. These showed how the components would work when implemented into the design. After this we started implementing the electronic components into the exhibit. This included coding, soldering, and wiring up the components. This step came with many challenges as there were multiple different components we planned on using. Problems with faulty components also proved to be a challenge and caused some minor setbacks. We also designed and 3D printed many parts that would serve as mechanisms for movement and others that were for aesthetic purposes.

After the majority of the individual components were working, we started implementing them into the design. This came with trial and error. Some of our original designs proved to have flaws in them, which forced us to redesign and create new parts. Once we had these components in place and functional, we started working on integrating them all together. We also worked on creating graphics for our exhibit so that it would appeal to the kids and look fun and exciting.

Due to the number of components we have, we decided to use two Arduino red boards which would communicate with each other and to the monitor through MATLAB. This proved to be challenging, but we were able to use serial port communication to direct each board. This is where we started implementing monitor graphics which also included instructional videos. Through MATLAB we were able to control the game so that it could function autonomously and reset on its own.

9.5 EVALUATION

To evaluate the success of our exhibit we will be focusing on three measures of success. The amount of time spent at the exhibit, the user's enjoyment, and their retention rate.

Our goal for our first measure of success is that 75% of the children will spend at least 1 minute at our exhibit. This will be timed and recorded in a file output from MATLAB.

Our second measure of success is the user's enjoyment. After completion of our exhibit we will ask the kids reflection questions to gather their enjoyment levels. To encourage their response we will be providing them with a small prize.

Our final measure of success focuses on the student's retention rate. This will be determined by how successful the kids are at playing each of our games. To succeed and do well at our compost collection game, the kids need to understand the main concepts of biogas. We will track the number of buckets successfully collected and compare this to the number of buckets filled with waste that is not suitable for biogas. We will also track how successful the kids are at our temperature game because this correlates to their understanding of major concepts.

The combination of these methods will allow us to thoroughly evaluate the effectiveness of our exhibit.

9.6 INDIVIDUAL CONTRIBUTION

I researched different aspects of an inclusive design and tried to ensure that we implemented them into our project. When figuring out the layout of our design I ensured that it included many of these principles like angled panels, easy to access buttons, open space, etc. I also tried to emphasize the importance of creating a layout that read left to right and had a flow to it. I helped design the front panel and created an assembly with all of the different parts of the exhibit and ensured that they fit together.

Building

When it came to the building process, I helped create drawings for some of our pieces in AutoCAD to laser cut. I also spent a lot of time modifying our base panel. Because we chose an angled design there were many different angled parts that were tricky to fit together. This was a challenge, but I was able to modify the design so that the base pieces fit together well. Once the pieces were cut, I helped assemble utilizing the pieces I had designed to support the structure. Throughout this process I communicated with my group mates and thought of potential issues to problems we had such as supporting the middle panel.

Compost Collection Game

I took charge of the main components for our compost collection game. Our main issue with this game was how to create linear motion from the radial motion of a servo motor. I proposed, and ended up designing a piece that allowed for these additional degrees of freedom that would allow the collector basket to move in a straight and horizontal line. I also designed pieces that would allow the servo motor to attach to the rod holding the basket. For the next main component of the game, the LED strips, I created code for them that created a falling effect. Once this was working, I soldered the LED strip segments as well as our buttons.

Tractor Mechanics

We ran into some issues with our tractor because we didn't have enough space to keep the radius from the pivot point constant, so I designed a similar mechanism as used in the compost collection game that added a degree of freedom allowing the radius to change and follow the path created for the tractor.

MATLAB and Monitor Integration

I also assumed responsibility for creating the serial port communication between Arduino boards and MATLAB. I learned how to connect them together and implemented my LED and servo motor code into the program. Unfortunately, our servo motors were faulty, and this consumed much of my time. Despite this I was able to get this part working and moved onto integrating the monitor. With the help of a groupmate for graphics, I integrated a display into the code. Using different plots for multiple images I was able to get the different icons to pop up before they “fell” down the LED strips. I also worked on other visual elements of this game as well.

Finally, I worked on integrating all our components with the help of my teammates, including the instructional videos and other games into one cohesive file. This allows kids to decide when to start and reset the exhibit when they are done playing.

Having project mentors was helpful because they helped clear up some of the confusion and uncertainty we had early on. Our mentor also helped us with the decision process of prioritizing different aspects of our project.

CAROLINE DIMAIO

10 INTRODUCTION

This report provides a comprehensive overview of the technical aspects involved in the design and implementation of a children's museum exhibit focused on biogas. The primary objective of the exhibit is to educate middle school students about the importance of sustainability and to introduce biogas as one practical approach to promoting a more sustainable environment.

10.1 PROBLEM STATEMENT

Sustainability education is currently falling short in effectively engaging adolescents. Existing teaching methods often overlook the principles of cognitive psychology, particularly how middle school students absorb, process, and retain information. As climate change continues to pose an increasing threat to future generations, it is imperative to develop more impactful educational strategies that help young learners understand the importance of taking proactive steps toward a sustainable future. In response to this challenge, our team developed a comprehensive design approach aimed at optimizing educational outcomes for this age group. We established specific criteria to guide the creation of the exhibit, prioritizing elements such as interactivity, creativity, and gamification – all essential for fostering engagement and enhancing the learning experience.

To effectively implement these educational strategies, we structured our exhibit using a tri-fold layout designed to create an inviting and accessible learning environment for middle school students. Central to our approach is the integration of gamification – a method proven to enhance learning by making it interactive, enjoyable, and participatory. Our research highlighted that gamification is particularly effective for this age group, as it incorporates a variety of instructional techniques that cater to diverse learning styles. These include hands-on physical demonstrations, interactive tasks, reward-based progression, and elements of friendly competition. To ensure that key concepts are understood and retained, the exhibit features multiple checkpoints that students must successfully navigate in order to advance through games. This approach encourages active engagement and reinforces learning in a playful, competitive manner, without overwhelming students with excessive reading or complex terminology.

10.2 STAKEHOLDERS

The primary stakeholders of our museum exhibit are the elementary and middle school students of Beachmont Elementary School. In order to tailor the design to meet the needs and preferences of this target audience, we carefully considered their cognitive development, learning styles, and areas of interest. Recognizing that children aged 6 to 14 – members of Generation Alpha – have been raised in a media-rich environment, we chose to deliver the educational content through a video game-inspired format. This approach aligns with the digital experiences they are accustomed to, whether at home or among peers, thereby increasing engagement and familiarity. Furthermore, all information presented in the exhibit was intentionally simplified and conveyed using concise language, age-appropriate references, and relatable examples to ensure clarity and comprehension.

10.3 REQUIREMENTS

The exhibit was designed to meet several specific technical and logistical requirements, including the integration of at least two Arduino components. We leveraged this requirement to enhance interactivity for the students by incorporating buttons for user input, LED strips for dynamic visual effects, and a servo motor to operate a hands-on compost collection game. Another constraint was adhering to a $100 budget. We successfully remained within this limit, primarily due to the availability of pre-owned materials, including Arduino components provided through our SparkFun kits. Additionally, the exhibit was required to feature a 3D-printed or laser cut element. To construct the foundation and overall structure, we used laser-cut plywood, precisely measured to fit our design specifications. To further elevate the educational and interactive experience, we incorporated several 3D-printed components, such as a bucket attached to the servo for the compost game, a tractor for the farm narrative, and various mechanical parts, including a connecting rod to enable servo movement. These elements contributed to both the functionality and thematic coherence of the exhibit.

10.4 ETHICAL CONSIDERATIONS

In the initial stages of developing our exhibit, our team intentionally applied principles of Value Sensitive Design (VSD) to ensure the experience would be inclusive and equitable for all users. As part of this approach, we carefully considered factors such as accessibility and usability across a diverse range of visitors. For instance, we evaluated the placement and height of text and visual elements to accommodate users of varying statures, ensuring that essential information was easily visible and comprehensible to all. We also employed clear, concise language to promote understanding regardless of reading level. Additionally, we incorporated familiar and approachable visuals – most notably, a farm-themed aesthetic throughout the tri-fold display – to foster an engaging and immersive environment that resonates with children and enhances the overall learning experience.

10.5 BIOGAS

The focus of our sustainability-themed exhibit is biogas, a renewable energy source generated through the process of anaerobic digestion. This biological process involves the breakdown of organic waste materials- such as food scraps, animal manure, and agricultural byproducts- by microorganisms in an oxygen-free environment. As the waste decomposes, it releases a blend of gases, primarily methane (CH_4) and carbon dioxide (CO_2). These gases are then captured, purified, and then utilized as a clean and sustainable fuel. Beyond serving as an alternative to fossil fuels, biogas production also plays a significant role in mitigating greenhouse gas emissions and diverting organic waste from landfills, thereby contributing to a more sustainable and environmentally responsible waste management system.

10.6 SCOPE

This report details the engineering design process undertaken in the development of both the initial prototype and the final iteration of our museum exhibit. It outlines the methodology used to generate, evaluate, and implement design solutions with the goal of optimizing the user experience. The proposed solution is presented in this report through a comprehensive overview of our design rationale, supported by AutoCAD sketches and descriptions of key physical components, all of which contributed to the successful realization of the final exhibit.

11 BACKGROUND

The design choices for our biogas-themed museum exhibit were informed by a combination of individual research, experiential learning, and observational analysis. A key influence was our service-learning experience at Beachmont Elementary School, where direct engagement with students in our target age group provided valuable insights into their learning styles, interests, and behaviors. In addition, a field visit to the Museum of Science in Boston offered further perspective on effective exhibit design. By observing how children interacted with various displays and noting which elements captured their attention, we were able to assess both successful and less effective design strategies in real-world contexts. Through these experiences, we collected qualitative data on student preferences, engagement triggers, and the types of interactive features they found most exciting. These findings played a crucial role in shaping our exhibit to be both educationally impactful and highly engaging for young learners.

11.1 INDIVIDUAL RESEARCH

As part of our individual research efforts, our team sought to deepen our understanding of three key areas critical to the success of our exhibit: student engagement strategies, the characteristics of effective museum exhibits, and the principles behind gamifying educational content. A central finding that emerged from our research was the importance of integrating cognitive psychology into exhibit design. Specifically, we focused on three foundational cognitive processes: (1) how students intake information, (2) how they process that information, and (3) how they retain it. By addressing each of these stages thoughtfully, we aimed to create an exhibit that was not only engaging, but also pedagogically effective.

To support the intake of information, our design emphasized sparking curiosity, stimulating the senses, and ensuring relevance to students' everyday experiences. To accomplish this, we incorporated bold, eye-catching visuals, immersive sound effects, and interactive features such as buttons, LED lighting, and mechanical components to foster tactile engagement. These sensory and experiential elements were intentionally chosen to draw attention and make the subject matter approachable and intriguing.

In the processing phase, our goal was to help students understand and internalize the core concept of biogas through a clear cause-and-effect sequence. We designed an activity where students would stimulate collecting organic waste, converting it to biogas, and then using that biogas as a renewable energy source. This hands-on representation of the biogas cycle allowed students to directly engage with the underlying scientific principles in a manner that was both interactive and memorable. A key aspect of this stage was the integration of gamification, which we used to sustain attention, increase motivation, and promote active learning. By embedding interactive games within the exhibit, we were able to maintain students' focus while reinforcing key educational messages.

Finally, for the retention phase, we considered strategies to ensure that students would remember both the content and the importance of biogas, rather than simply recalling the gameplay. To reinforce learning, we incorporated reflective questioning immediately following the interactive experiences to assess comprehension and encourage critical thinking. Additionally, we introduced game-based checkpoints that required students to recall information presented in an instructional video in order to progress. To further support long-term retention, we developed a take-home element designed to serve as a tangible reminder of the exhibit and its sustainability message, reinforcing the learning experience beyond the museum setting.

11.2 SERVICE-LEARNING EXPERIENCE

Our service-learning experience at Beachmont Elementary School provided a unique and invaluable opportunity to engage directly with the primary users for whom our exhibit was being designed. This firsthand interaction allowed us to gain deeper insight into the interests, behaviors, and learning preferences of elementary and middle school students. Through structured learning activities and informal conversations, we observed how students interact with educational content, what captures their curiosity, and how they process and retain information in an interactive environment.

One of the most significant takeaways from this experience was the importance of truly understanding one's target audience. Designing an exhibit for users who differ significantly in age and cultural context – especially those from a younger generation with distinct experiences, interests, and modes of communication can present considerable challenges. These students have grown up with different technologies, engaged with different types of media, and possessed unique frames of reference shaped by their generational context. However, the time spent with them enabled us to momentarily step into their world and gain a clearer perspective on their mindset and preferences.

This immersive understanding informed many aspects of our design, from the selection of visual and thematic elements to the interactivity and complexity of the content. By developing empathy for our users and grounding our design decisions in real-world observations, we were better equipped to create an exhibit that is not only educational but also enjoyable and meaningful for the students it was intended to serve.

11.3 PERSONAL CONTRIBUTIONS

While the core focus of my research centered on the cognitive psychology principles outlined in Section 11.1- specifically, the stages of information intake, processing, and retention – I also explored a range of sustainability topics during the initial phases of the project. One area of particular interest was the reduction of carbon dioxide (CO_2) emissions through carbon capture technologies. I was drawn to this topic not only for its scientific and environmental significance but also for its potential to be translated into an engaging, child-friendly educational experience. Recognizing that trees- natural carbon capturing organisms – are widely familiar and easily understood by children I envisioned a concept that would use this association to communicate the idea of carbon capture in a relatable and approachable way.

My research involved examining how carbon capture works, its critical role in mitigating climate change, and the technologies currently being developed and implemented to support this process. I then began exploring ways to gamify this complex topic to make it both educational and engaging for younger audiences. Based on my findings, I developed a proposal for an interactive game in which students would "collect" CO2 molecules to clean up a digitally stimulated polluted city. The gameplay would mirror the natural role of trees and carbon capture technologies in purifying the atmosphere, thereby creating an intuitive connection between the real-world issue and the exhibit experience.

In designing this concept, I applied the three-stage cognitive learning model I had previously researched. To support information intake, the exhibit would feature bold, colorful visuals and sensory stimuli such as button and animations to draw students' attention. For the processing stage, the gameplay mechanics would illustrate the cause-and-effect relationship between carbon capture and environmental restoration. Finally, to aid retention, I proposed a take-home element- such as tree seeds- to provide a tangible reminder of the exhibit and empower students to feel personally involved in the movement toward a more sustainable future.

12 METHODOLOGY

This section of the report outlines the rationale, objectives, and implementation strategies involved in the development of our final museum exhibit, detailing the progression from the initial brainstorming phase to the completed design.

12.1 PROBLEM DEFINITION

Before generating any exhibit concepts, our team prioritize defining and thoroughly analyzing the problem, along with its associated complexities. To begin this process, we created an empathy map to explore the user experience from the perspective of our target audience. This tool allowed us to consider how students might currently feel when interacting with traditional educational exhibits, what challenges they may face, and what types of experiences would most benefit them. By engaging in this reflective exercise, we were able to gain a deeper understanding of our users' needs, preferences, and learning styles – insights that were critical to designing an exhibit that would be both effective and engaging.

Following the empathy mapping, we moved into the next phase of our problem analysis determining which educational outcomes would be most valuable for the students. Each team member conducted independent research on various teaching strategies and sustainability topics to help narrow the scope of the exhibit's content. Once a central theme was selected, the team collaboratively identified the essential components and design benchmarks needed to bring the concept to life. These included ensuring that the exhibit would be fun, interactive, intellectually stimulating, and rewarding for users. By establishing these foundational goals early in the process, we were able to align our design decisions with our overarching objective – to create a meaningful and enjoyable learning experience for young students.

12.2 SOLUTION GENERATION

In order to generate well-informed and effective design solutions, each team member conducted individual research focused on identifying the most impactful educational strategies, methods for enhancing student engagement, and approaches to promote long-term information retention. This research phase was foundational in shaping the direction of our exhibit, as it allowed us to evaluate evidence-based practices and tailor our design to suit the cognitive and behavioral characteristics of our target audience.

One of the most significant findings across all team members' research was the consistent effectiveness of gamification in engaging elementary and middle school students. Numerous studies have shown that integrating game-like elements into educational content increases motivation, sustains attention, and improves learning outcomes, particularly in younger learners. This conclusion strongly influenced our design philosophy, leading us to prioritize interactivity and play-based learning as core components of the exhibit.

In parallel, research was conducted to identify a sustainability topic that would both be relevant and impactful for students within this age group. Our goal was to select a subject that not only addressed a current environmental issue but also offered opportunities for students to understand their potential role in contributing to a more sustainable future. We evaluated each topic based on its educational value, feasibility for gamification, and capacity to foster a sense of empowerment and responsibility in young learners.

This research drew from a variety of academic sources, including peer-reviewed journals, educational studies, and sustainability reports. In addition to traditional research methods, we also engaged in experiential learning through our service-learning partnership with Beachmont Elementary School. During this time, we asked students questions to assess their prior knowledge and familiarity with various sustainability concepts. For instance, we inquired whether they had heard of topics like biogas or carbon capture, and what associations or ideas came to mind when they heard the topics. These conversations provided valuable qualitative data that helped validate our research findings and ultimately guided the selection of a topic that was both age-appropriate and intellectually engaging.

12.3 DECIDING ON A SOLUTION

To select the most suitable sustainability topic from among four researched options, our team employed a Kepner-Tregoe Decision Analysis (KTDA) chart to guide and inform our decision-making process. Each proposed topic was evaluated based on four primary criteria: interactivity, visual appeal, educational value, and feasibility of production.

Within the interactivity category, we assessed the potential for gamification, inclusion of moving parts, and the extent of hands-on or physical engagement. Visual appeal was evaluated through factors such as colorfulness, reliability, functional design, and the capacity to capture and maintain user interest. For educational value, we considered the topic's relevance to sustainability, its ability to be simplified for an elementary school audience, and the potential for incorporating meaningful take-home elements, Lastly, the feasibility of production was measured by analyzing constraints such as physical size, ease of implementation, and the extent to which the exhibit could operate independently.

Each team member independently rated all topic proposals on a scale of 1 to 10 for each criterion. Upon compiling the results, biogas emerged as the most viable and impactful topic, receiving the highest overall score based on its strong performance across all categories.

12.4 IMPLEMENTATION

To implement our exhibit design, the project was divided into four key components: the infographic panel, the compost collection panel, the biogas digester panel, and the base of the board, which featured a cohesive farm narrative tying the elements together. Each team member selected one panel to develop and was responsible for creating detailed visual representations using AutoCAD and SolidWorks. These designs were presented to the group, and after collaborative discussion, we finalized a unified design that aligned with our intended user experience.

With the overall structure agreed upon, we focused on critical considerations such as the exhibit's logical flow, the sequence of user interaction, and the educational takeaways at each stage. Keeping these factors in mind, each team member began integrating interactivity, gamification elements, and visual cues into their assigned panel to create the initial prototype.

During the prototyping phase, peer feedback played an essential role in identifying design limitations and opportunities for refinement. This iterative process helped us pinpoint necessary modifications and informed the next steps toward achieving a fully integrated exhibit. Once we had individual components functioning independently, our focus shifted to ensuring seamless interaction between all elements, thereby enhancing the overall user experience.

In the final stages leading up to project completion, we dedicated time to polishing the aesthetics of the exhibit, finalizing and compiling our technical report, and resolving outstanding technical issues such as code debugging. These final adjustments ensured a cohesive, engaging, and educational experience for our intended audience.

12.5 EVALUATION

To evaluate the effectiveness of our prototype during the peer review phase we developed a structured feedback form using Google Forms. This form was distributed to each visitor who interacted with our exhibit and included a series of targeted questions designed to assess user experience and gather constructive feedback. Respondents were asked to rate their overall level of satisfaction, identify any aspects of the exhibit they found less effective or unenjoyable, highlight elements they particularly liked, and offer general suggestions for improvement.

The feedback collected through this process provided valuable insights into the strengths and weaknesses of our prototype. Common themes and recurring recommendations were carefully reviewed and used to inform a series of strategic revisions. These adjustments played a key role in refining the exhibit and ensuring that the final product presented at the expo was both engaging and educationally impactful.

12.6 INDIVIDUAL CONTRIBUTIONS

As part of my individual contribution to the success of our museum exhibit, I focused primarily on the visual design and ensuring comprehension of our chosen topic to the target audience. During the early stages of the project-specifically Milestones 2 and 3, which involved the structural design of the exhibit – I emphasized the importance of exhibit flow, advocating for a left-to-right progression to align with natural reading patterns and enhance user comprehension.

I also underscored the importance of making interactive components easily accessible and physically engaging. Drawing on both my individual research and insights from our empathy map, I highlighted the role of sensory interaction – what users can feel, see, and experience – as a critical factor in promoting engagement and retention.

During the prototyping phase, I took primary responsibility for the infographic panel, which served as the educational introduction to our exhibit prior to the gamified components. I conducted research on how to distill complex scientific processes, such as biogas production, into simple and age-appropriate explanations. This involved leveraging a combination of visual storytelling, short videos, and simplified diagrams to ensure that the content was both engaging and comprehensible for elementary and middle school students.

In addition, I curated the overall visual aesthetic of the exhibit, including the color scheme, graphics, and imagery. My goal was to create a cohesive and inviting visual identity that aligned with our farm-based narrative while capturing students' attention through bold, vibrant design elements. These efforts played a key role in drawing students into the experience and supporting both educational and emotional engagement with the content.

My experience working with our peer mentor, Sean Jaffe, was both valuable and insightful. Engaging with someone who had previously completed the course successfully provided a unique opportunity to gain perspective, refine our ideas, and receive constructive feedback. I found the interaction particularly beneficial for problem-solving and discussing potential design improvements. It was encouraging and helpful to speak with someone who had navigated similar challenges, and his guidance served as a meaningful resource throughout the development of our project.

FART TO FUEL

13 FINAL DESIGN

13.1 EXHIBIT OVERVIEW

The final design consists of four modular components, assembled in a trifold pattern with a base connecting the walls. Each of the panels are approximately twenty inches tall, divided into two panels connected by a board set at 135 degrees.

The left most panel is twelve inches wide and functions as a source of information, highlighting entry level information about the biogas collection and conversion process using cartoon-esque images. This can be seen in **Error! Reference source not found.**

The middle panel is wider, at fourteen inches, and adds a depth of approximately **4 inches**. This panel is used to house the first game component of the exhibit, being the collection process of biogas creation. The top panel has a **6.75in x 8.25in** cut-out to allow for the view of an iPad screen, which is held up by wood supports. Under the monitor are four evenly spaced notches, through which LED strips run – down the board, then back behind through holes in the bottom panel. From the front, a basket is visible sitting on a track, capable of motion left and right. From behind, the basket is attached to a servo system designed to convert the rotational motion of the servo into linear motion, visible in **FIG** The servo is secured in a holder glued to the base of the panel, with a rod attached to the servo arm. The rod passes through a circular joint connected to the basket, which allows for vertical movement along the rod. This mechanism creates the illusion that the rod is moving left and right as the servo changes angles.

The right most panel matches the façade size of the left panel but includes additional side and back supports, along with multiple electronic components. Centered across the top and bottom panels are halved rubber tubes, of **1.5in** diameter and **2in** diameter respectively, which are connected by smaller tubes of **.5in** diameter. Hidden behind the larger tube is a small water reservoir, with an atomizer and led attached. To the right of the **1.5in** tube is a small servo with a needle tip attached to the end atop a cartoon temperature dial. A crank is attached to the right edge of the panel, with additional supports around it to prevent instability during use. Along the bottom third of both side panels are two screw holes used to connect to the base using thumbscrews and wingnuts. *

The base encompasses two smaller pieces, connected by an interlinking system consisting of three triangles which fit together to resist linear forces and keep the parts attached. The top face is a trapezoidal shape, designed to fit cleanly against the three panels. It is elevated to create a slight downward slope towards the users. Along the front of the base are four buttons, which have the wires concealed within. Also within the base is a servo system, connected to an elongated arm connected to a tractor visible above the base. There is an arc cut out to match the path of the tractor. The arm connected to the tractor uses a similar system to the one used to in the middle panel allowing for the radius of the tractor to change, minimizing the system getting stuck along the wood. A detachable cover runs along arc's, designed to fully conceal the internal electronics. An image of this with the cover removed can be seen in **Fig. 2**.

The components and materials can be referenced within Appendix L.

13.2 USER EXPERIENCE

Upon approaching the exhibit, we expect users to engage in a left to right order, aided by the visual guiding of the tri-fold design. The user will briefly read the information available on the left panel. Then, the user will press the highlighted button to start the game.

A short video will play on the monitor, providing a simplified explanation of the biogas process and potential uses. This transitions to an explanation of the collection game, providing the rules and instructions necessary to play. Once the game begins, the monitor will display multiple types of waste, each corresponding to the LED strips below. The LEDs will move down the strip, towards the basket. The user must use the left and right buttons to move the basket to catch the appropriate waste, as indicated by the icons on the monitor. This information is also on the information panel for reference. A bucket icon will appear on the screen, filling up as good waste is collected and emptying if bad waste is caught. Full buckets will be displayed at the top of the screen and will continue to update until the game ends.

After the collection game, the experience transitions to a new game, introduced by a short explanatory video. In this game, users must manage the temperature of a biogas digester. One player holds down a button to move a servo that represents the temperature gauge, while another player simultaneously turns a crank on the side. If both actions are performed concurrently for a sufficient amount of time, the game ends successfully.

Finally, a button with light up and users must press it to initiate the motion of the tractor on the base, demonstrating the use of biogas. This acts as a conclusion to the game, and a short reward for the successes.

As users begin to leave, team members will invite them to complete a short questionnaire to assess their learning and enjoyment. Those who complete it will receive a small prize.

A descriptive flowchart outlining this interaction is available below, **Error! Reference source not found.**.

13.3 FUNCTIONAL COMPONENTS

The design features several non-standard mechanical design elements that are essential to its functionality and user experience.

One key mechanism involves a vertical rod connected to a servo motor, slotted through a circular ring attached to the basket. As the servo rotates, the ring slides up and down the rod, maintaining the basket at a consistent height while allowing it to shift left and right—this ensures smooth lateral movement without vertical displacement. Visual of this mechanism is seen in Appendix E.

Another rod-servo mechanism is employed to move a miniature tractor across a controlled arc with minimal resistance or deviation. The same circular ring attachment is attached to the tractor's base, which a rod connected to a servo is slotted through. As the servo turns, the radius of the tractor can change, thus assuring it is always apt for the arc.
For panel connections, a unique triangular joint system is used: two triangles face inward, and one faces outward, creating a locked configuration that prevents panels from separating unless lifted vertically—this method ensures structural stability without the need for complex fasteners. Additionally, a water reservoir incorporates a small hole linking it to a larger container, feeding water to an Arduino-controlled atomizer. This design minimizes the risk of overflow while ensuring consistent water supply.

13.4 ELECTRONICS/SOFTWARE

Monitor Display

To present our instructions and game visuals, we used a mounted iPad as an interactive display. The software responsible for managing the visuals and game sequence was developed in MATLAB and run on a laptop. MATLAB displayed game visuals in a separate window, which was mirrored to the iPad using an application called Spacedesk.

Our design consisted of two separate Arduino boards that communicated with MATLAB through serial port communication. The Arduino code for the servo motor and LED strips can be seen in appendix G, along with the MATLAB code. The wire diagrams for our setup can be seen in appendix G.

Introduction

To allow our exhibit to run smoothly and rest itself, we utilized MATLAB code that controlled the Arduino boards. To start the exhibit one of the middle buttons lit up blue and showed a screen to tell the user to press the button to start. After the button was pressed the first instructional video would play.

Compost Collection Game

After the video finished, the compost collection game would start. The two middle buttons light up signifying which ones to use. This portion of the MATLAB code starts by calling for a randomized type of waste and which strip to fall down. It also signals Arduino to start the servo code. With both working, the Arduino returns an angle number which corresponds to a certain strip. This allowed us to check if the waste was collected. If waste was collected a corresponding “good” or “bad” audio sound would play. Further the bucket amounts would update. After this game finished, a picture of the number of buckets collected on the screen was shown so that the user could see their progress.

Temperature Crank Game

After this the second instructional video plays. Following this video, the temperature game starts, and the corresponding button LED turns on. For this game a stop motion animation video play. It only plays if the temperature servo is within the correct angle range and the number of cranks is increasing. If one of these is not true, the animation pauses, and no biogas is created.

Tractor (Saving the Chickens)

After the completion of this game, an image of the tractor instructions is displayed, and the corresponding tractor button lights up. When the tractor button was pressed (and the temperature game was finished), the tractor would move to the ends towards the chickens. It would then reset itself when the game was finished. Once the chickens were saved, a celebratory audio clip is played. Following this, different variable values to evaluate how well the users did are written in a text file. The MATLAB code is on an infinite loop so after this, the whole game resets and is ready for the next player. Our game play flowchart can be seen in Figure 2.

All component wire inputs and corresponding Arduino pins are outlined in Appendix M.

13.5 FIGURES

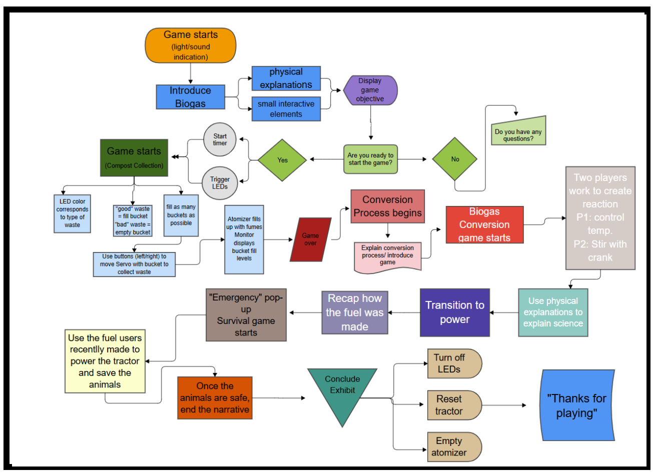


Fig. 2 - Labeled Image of the Flowchart

Fig. 1 - Fully decorated final design, with base cover removed

14 RESULTS

14.1 QUALITATIVE DATA

Qualitative data was taken through a post-interaction questionnaire. As an incentive, a small prize was offered upon completion. This data was used as a metric to understand the student enjoyment and accessibility in the design.

Through this survey, we found Through this survey, we found that students, overall, found the exhibit fun and engaging. Their feedback highlighted that the hands-on elements provided compelling visuals and tactile interactions that encouraged participation. Users expressed interest in the video explanations, even without direct interaction, likely due to the fast-paced editing style and integrated humor that kept their attention. Additionally, the games created opportunities for collaboration, allowing multiple users to participate at once and share the experience. The physical components, such as the temperature and crank stations, were especially well-received—students enjoyed the chance to move and be expressive, which stood out from more passive exhibits. These results indicate success in designing an exhibit that caters to the preferences of a younger demographic by incorporating interactivity, humor, and opportunities for movement.
A breakdown of the feedback given by the users can be seen in Appendix F

14.2 QUANTITATIVE DATA

The quantitative data was collected through the tracking of results directly from the games. In the first game, the number of buckets successfully filled served as an indirect measure of understanding waste categorization and properties. In the second game, success rates reflect the user's grasp of the necessary conditions for biogas conversion.

These metrics provided valuable insight into the exhibit's educational effectiveness. The results showed that students were able to quickly adapt from initial mistakes, demonstrating the productive failure model in action. Users learned the correct information through repeated gameplay and retained it long enough to articulate their understanding afterward. The waste sorting statistics indicated a strong ability to differentiate between materials and recognize qualities suitable for biogas production. Moreover, all participants were able to verbally reiterate key points of the process to exhibit attendants, showing not only retention but comprehension of the material.

Through this method of integrated data collection, we were able to reasonably justify that the exhibit succeeded in delivering its educational goals while maintaining a fun, interactive, and collaborative experience for younger audiences. The collected data can be seen in Appendix F.

JONATHAN CHAN

15 DISCUSSION/ANALYSIS

Our final exhibit design successfully incorporated the key elements and interactive techniques we set out to implement, capturing a balance between educational value and user engagement. It met all logistical and functional requirements, including constraints related to size, budget, and transportability. More importantly, the hands-on components of the exhibit proved to be the most impactful—users consistently highlighted their direct interactions as the most enjoyable and memorable parts of the experience. The design effectively guided students to retain key biogas concepts, particularly around waste types and energy conversion conditions, which were central to our educational goals. These outcomes demonstrate that our design choices not only captured attention but also facilitated clear and meaningful learning in a dynamic, engaging agenda.

15.1 EASILY MEASURED GOALS AND REQUIREMENTS

The final exhibit met all key measurable goals and constraints established early in the design process. It fit within the designated table dimensions for the expo and could be fully assembled in under 15 minutes. All components were compact and portable, easily fitting into a single transportable bag. The project stayed within budget, coming in under the $100 limit with approximately $40 to spare. Functionally, all game features operated smoothly and reliably, even after repeated use throughout the day. The design was also child-safe, with no sharp edges or hazardous components, making it appropriate and engaging for a young audience.

15.2 HARDER TO MEASURE GOALS AND USER ENGAGEMENT

In addition to meeting the easily measured constraints, the exhibit also addressed several harder-to-measure goals focused on user engagement and educational impact. During the expo, user data was collected in two primary ways. MATLAB was used to track quantitative data such as the win rate of the waste collection game and the amount of time each student spent engaging with the exhibit. This automatic data collected by MATLAB could be viewed in Appendix F. In-person observations and interactions also provided valuable insights: students were encouraged to share their thoughts on potential real-world applications of biogas during a final discussion, and they completed a stamp-based survey to rate their overall experience. These combined methods offered a more holistic view of user engagement, helping us assess both enjoyment and retention of key concepts.

15.3 EDUCATIONAL GOALS

Our exhibit aimed to teach children the fundamentals of biogas production through a mix of concise educational videos, interactive gameplay, and visual feedback. Each game station was paired with a short, engaging video that introduced the science behind the activity in a way that was easy to understand. This set the stage for hands-on learning and helped reinforce key concepts throughout the exhibit.

One of the main attractions was the compost sorting game, which required users to distinguish between waste types. With each correct or incorrect choice, the game played audio cues—modeled after popular games—that provided instant feedback. Children responded enthusiastically to this feature, quickly learning to identify which waste items could be used for biogas. On average, they collected between 3 and 4 buckets of "good" waste, and their performance improved over time as they played multiple rounds.

We also closely observed reactions to our second activity—the temperature game. This involved generating and maintaining energy levels by cranking a handle and pressing a button to simulate the temperature control process in biogas production. What stood out was the direct correlation between a user's efficiency in the game and their sustained engagement. Children who managed to crank faster were also the ones most likely to stay engaged throughout the entire exhibit. Their physical participation translated into mental focus, and their reactions—cheering when successful or determinedly retrying when not—indicated a deep investment in the learning experience.

To further assess learning, we offered poop-shaped prizes after the game. Kids who wanted to earn more were prompted with follow-up questions about biogas and waste types. Many answered correctly, demonstrating clear learning retention.

Overall, the combination of educational media, active gameplay, and immediate feedback created a compelling, multi-sensory experience that kept children engaged while effectively teaching the science of biogas.

16 CONCLUSION

The given problem asked us to develop a sustainability-focused exhibit that could truly engage elementary and middle school students, especially those from under resourced backgrounds. Traditional teaching methods often rely on passive forms of learning, and we wanted to challenge that norm by creating an educational experience that kids would want to engage with. Our goal was to design something tactile, interactive, and story-driven that sparks curiosity and leaves a lasting impression—not just about sustainability, but about how engineering and technology can solve real-world problems.

Our developed solution was a hands-on biogas exhibit that blends humor, storytelling, and physical play. It begins with a compost sorting game where students separate usable waste from trash, and continues into a two-part demonstration of biogas production—tracking mixing and heat, and culminating in a story-driven finale where the energy produced saves a group of chickens via a powered tractor. Each element had a purpose: LEDs created visual feedback, servos provided physical movement, and encoders tracked user input—all orchestrated through Arduino and MATLAB. Several functional buttons were installed to stimulate the children's drive to play with our exhibit. With a built-in educational video system and an engaging user interface on the iPad, the exhibit was both informative and fun.

In addressing the original problem, we prioritized the student experience above all else. We didn't shy away from using humor—specifically bathroom humor—as a tool to break the ice and meet kids where they are. This made the topic more approachable and helped form emotional connections to the material. Kids weren't just playing a game—they were learning how waste becomes energy, and they were doing it in a way that made them feel empowered and capable. The open design of our exhibit allowed them to preview activities before engaging, which built confidence, while the story-based structure helped them see how sustainability is tied to real-world outcomes.

The design process was essential in making this project successful. By following a structured engineering design approach, we started with research, clearly defined our objectives, and set criteria that reflected our target audience's needs. Generating a wide range of ideas gave us creative freedom, and tools like decision matrices kept our process grounded and focused. Prototyping with cardboard helped us visualize the physical layout early on and make practical changes. Our final exhibit reflected weeks of iteration, including real user testing and feedback loops, where we used student responses and tracked engagement to refine the product further.

The potential impact of this exhibit goes beyond just one classroom or expo. It opens the door for younger students—many of whom may not normally have access to engineering content—to see themselves as future problem-solvers. By combining accessibility with fun and functionality, we hope to inspire the next generation to care about sustainable systems and engage with STEAM fields. The storytelling, interactivity, and humor created an experience that resonates emotionally and intellectually, which is the kind of learning that sticks.

Overall, this project has demonstrated the power of intentional, student-centered design in tackling real educational gaps. It stands not only as a tool for learning, but as a template for future exhibits and outreach strategies aimed at equity, inclusion, and impact.

17 RECOMMENDATIONS

After reflecting on insights shared by students, peers, and mentors, there is vast opportunity for improvement to create an experience more interactive, memorable, and impactful for everyone involved.

Arduino Pin Layout:

A recommendation for improving the prototype is to create a more organized and well-thought-out Arduino pin layout. During development, we found it challenging to track which pin was connected to which component, especially since we used two Arduinos and multiple detachable panels. The wiring became disorganized, which led to confusion and delays during setup. To resolve this, a clearer pinout diagram and color-coded wiring could help streamline connections. Additionally, using modular connectors and creating a flexible wiring system for the detachable panels would make the setup process more efficient and reduce troubleshooting time, ensuring a smoother and more reliable experience.

Improved and Consistent Visuals:

A recommendation for improving the prototype is to establish a cohesive visual theme for both the exhibit and its instructional videos. During development, we noticed that our exhibit lacked a unified design, which made it less visually appealing compared to other exhibits that used popular, relatable themes like "Minecraft" or TV shows. Additionally, the instructional videos suffered from inconsistent visual elements, such as varying fonts and character designs, which detracted from the overall experience. By selecting a consistent color scheme, font, and character style across the exhibit and videos, we could create a more engaging and professional presentation. This would enhance the overall aesthetics and make the educational content feel more cohesive and immersive for the students.

Electronics Reliability:

A key recommendation for improving the exhibit is to enhance the structural integrity and the reliability of the electronics, particularly the servos. During testing, we encountered frequent failures with the servos, which would often become overloaded with information from both the Arduino and MATLAB, leading to malfunctions. This issue was most noticeable when the tractor servo failed to operate at the beginning of the Beachmont expo, resulting in a technical difficulty that deterred many kids from engaging with the exhibit. To address this, we recommend purchasing higher-quality, more durable servos with better load tolerance, as well as optimizing the communication between the Arduino and MATLAB to prevent information overload. This would help improve the exhibit's reliability, ensuring a smoother and more engaging experience for visitors.

18 LESSONS LEARNED

18.1 CONTRIBUTIONS

CAD / 3D Printed Components:

For the exhibit, I was in charge of creating all 3D printed components as I was the only member who possessed the credentials and knowledge to use the extruder machines.

1.Tractor/Chicken Coop:

The tractor and chicken coop was one of the most visually recognizable and mechanically active parts of the exhibit. Utilizing the useful resources and collaborative creations of users online, I was able to find pre-CADed files of these aesthetic elements that can accredited to in the works cited [25] and [26].

2. Crank Handle:

The crank handle was one of the most iterated components I worked on. I designed it with durability and user comfort in mind, knowing that it would be used frequently by children throughout the exhibit. The original version was too long and unwieldy, so I redesigned it to a shorter length for better torque control. I also added a spherical ball attachment that made it easier and more comfortable for children to rotate. The final version was both kid-friendly and mechanically reliable during all phases of testing. This design could be viewed in Appendix E.

3. Basket System:

While the basket system was CADed by my cornerstone teammate Eva, I took responsibility for preparing it for final use. Specifically, I sanded down some of the sharp edges and made slight adjustments to improve its functionality. These modifications helped calibrate its slidability across the monitor panel, which was essential for ensuring smooth interaction during the tractor sequence of the exhibit. This design could be viewed in Appendix E.

4. Temperature Dial:

I designed and CADed the temperature dial to match the length of the temperature needle, giving the temperature game a more aesthetically clean and finished look. The dial was designed not only for alignment accuracy with the potentiometer underneath but also for ease of user interaction, providing a simple and intuitive interface that was consistent with the rest of the exhibit's visual style. This design could be viewed in Appendix E.

Temperature Game:

One of my key contributions to the project was designing and coding the logic behind the temperature game, which formed a central part of the exhibit's interactive experience. This game was developed as a cooperative two-player challenge that required both users to work together to simulate gas production in an educational and engaging way. In the game, Player 1 was responsible for spinning a crank handle, while Player 2 managed the temperature dial by rapidly pressing a button to maintain a stable temperature. The goal for Player 2 was to keep the temperature needle within a range of 40°C to 60°C, while working against an internal resistance coded to continuously decrease the temperature over time. This meant the player had to constantly spam the button to fight against the resistance and keep the needle in range.

The system was programmed so that gas production only occurred if both conditions were met: Player 1 was actively cranking at a sufficient rate, and Player 2 had the temperature within the required range. When both players met these criteria, an interactive display linked to the system would play a frame-by-frame animation of gas being produced. However, if one or both players failed to meet the requirements, the animation would stop progressing. This real-time feedback system helped users clearly understand the importance of maintaining both actions simultaneously, reinforcing the educational theme of teamwork in energy production.

Creating this game required significant calibration and balancing, particularly in fine-tuning the temperature resistance logic and crank speed thresholds. I had to adjust how quickly the temperature dropped when the button was not pressed, how much each button press increased the temperature, and what counted as an "active" crank in terms of rotations per minute. Additionally, syncing the communication between Arduino and MATLAB to read both physical inputs and control the animation display in real time required careful coordination. I iterated through multiple test rounds to ensure that the resistance values and responsiveness made the game challenging yet fair, especially for the younger users at the Beachmont Expo.

In addition to the game mechanics, I also conducted research on how to integrate the rotary encoder for the crank handle and the servo for controlling the temperature needle. I researched how the rotary encoder could accurately measure the number of rotations of the crank and how this data could be translated into the game's logic. The rotary encoder converts the physical rotation of the crank handle into electrical pulses that the Arduino reads, allowing us to track the crank's movement. I also explored how to use a servo motor to control the temperature needle's position in response to Player 2's button presses. The servo allowed for precise control over the needle's movement, which was necessary for reflecting changes in the temperature within the game.

I focused on ensuring that both the rotary encoder and the servo were properly integrated into the game, ensuring that the actions of both players were synced correctly. The combination of the crank handle's movements and the temperature dial's adjustments needed to be responsive and smooth, which required a deep understanding of how each component interacted. Through research and testing, I was able to fine-tune the system, ensuring that the gameplay felt intuitive and engaging for players.

Ultimately, this coding work brought the temperature game to life, combining physical interaction with digital output in a way that was both fun and educational. Feedback from testers confirmed it was a highlight of the exhibit, and I'm proud that my work helped create a memorable experience that illustrated scientific principles through hands-on teamwork. The code behind the game can be viewed in Appendix G.

18.2 RESOURCES

Our group was well under budget, and a detailed breakdown of our expenditures can be found in Appendix L. Personally, I did not make any direct purchases for the project. Instead, I obtained critical components, such as the rotary encoder and servos for the temperature game, through FYELIC, which significantly helped us stay within budget. I devoted a considerable amount of time to the project, particularly on coding the temperature game and ensuring its functionality. Over the course of the project, I dedicated approximately 103 hours, which is documented in Appendix M.

This experience has helped me better understand the importance of resource management, particularly when working with limited budgets. Although I didn't spend any personal funds on materials, I saw firsthand how borrowing and reusing components can be just as effective in completing a project without compromising quality. This project also highlighted the value of careful planning, as utilizing the resources from FYELIC allowed us to focus more on the design and functionality rather than financial concerns. Moving forward, I'll approach resource management more strategically, ensuring that we prioritize sustainability and cost-effectiveness by leveraging existing materials and resources whenever possible.

18.3 REFLECTIONS ON LEARNING

This project taught me the importance of collaboration, problem-solving, and adaptability, especially when working with a team of diverse skills. I gained hands-on experience in integrating hardware and software, particularly in how to interface servos and sensors with Arduino and MATLAB. A key new experience for me was working with a rotary encoder in the context of a physical crank mechanism, and the challenge of combining physical construction with real-time software interaction. I also had to teach myself how to code logic for the temperature game, calibrating the interactions between components for a smooth experience. This project has given me valuable skills in hardware-software integration, troubleshooting, and project management, which will be beneficial for my future career in mechanical engineering and robotics.

18.4 REFLECTIONS ON EDP

Looking back on my experience with this project, I realize that the problem definition phase is something I would take even more seriously in the future. I learned that clearly understanding the end-user's needs and constraints from the start is crucial. In future projects, I plan to spend more time early on engaging with stakeholders—whether it's through interviews or surveys—to get a clearer picture of what the problem really is. This way, I can focus my efforts on the right areas and ensure the solutions I come up with are truly addressing the core issues.

When it comes to solution generation, I'm comfortable with brainstorming, but I see now that I could stretch my thinking further. I'd like to push myself to explore a wider variety of ideas and solutions. In the past, I often found myself jumping to conclusions too quickly, but now I understand the value of diving deeper into more creative and diverse approaches. Collaboration is key here, too, so I'll make sure to create a more open space for others to share their ideas and challenge mine.

In terms of communicating decisions, I feel confident in my ability to explain my design choices, but I know I can do better at justifying my decisions to both technical and non-technical team members. Reflecting on this project, I realized that I often assumed others would just understand the rationale behind my choices, but I see now how important it is to make sure everyone is on the same page. Going forward, I'll be more deliberate in explaining my thought process and the reasoning behind each decision.

For future implementations, I want to focus on improving the prototyping and testing phases. The project showed me the value of iterating quickly and gathering feedback along the way. I think I could have made adjustments more efficiently if I had tested prototypes earlier and more frequently. Additionally, I plan to keep better documentation of the design and implementation process, so it's easier for others to follow and understand the decisions made.

Finally, I've learned that evaluations need to be more structured and thoughtful. In this project, I could have gathered more specific data to measure the success of our design. I'm now aware that evaluations shouldn't just be based on personal impressions or feedback, but should also include quantifiable metrics. Moving forward, I'll set clearer goals for evaluation and ensure I'm using both qualitative and quantitative data to assess how well the design works and where improvements can be made.

18.5 REFLECTIONS ON WORKING IN A TEAM

This project has been a journey of both technical growth and personal reflection. Throughout this process, I've learned a lot about myself as a team member and the dynamics of collaboration. One significant shift in my team-working skills was learning how to adapt to different working styles and perspectives. Our team had a diverse set of skills and approaches, and while this was an asset, it also presented challenges. For example, when working with children at the Beachmont Expo, we had to make our temperature game both educational and fun. The experience taught me how to communicate more effectively with teammates who had different ideas, making sure everyone's input was valued while still staying focused on our shared goal. It also made me realize that flexibility is key to a successful team dynamic—especially when working on something that needs constant tweaking to meet the needs of the audience.

The biggest challenge I personally faced was stepping outside of my comfort zone with SparkFun components and real-world applications of code and hardware. Prior to this project, I had never combined coding and physical hardware in such an interactive context. I had worked with servos and buttons before, but integrating them with an interactive display and syncing everything together was a whole new ball game. The process of connecting Arduino with MATLAB to control the game mechanics in real-time was both daunting and exciting. I had to teach myself a lot along the way, from learning how to calibrate hardware responses to coding a dynamic system that could be easily adapted during live interactions with the children. The technical challenges were one thing, but the real-time feedback from kids at the expo pushed me to think on my feet and refine our system in ways I hadn't anticipated.

One of the most valuable lessons I learned was how to balance my technical skills with the creativity required for designing an interactive experience. While the technology was important, making sure the game was accessible and fun for children was just as crucial. The challenge was not just about ensuring the hardware worked, but also about making it intuitive and enjoyable for a younger audience. That said, I also learned that I need to be better at delegating and trusting my teammates more. Sometimes I found myself taking on too much, believing it was quicker to do things on my own, but this project really showed me how essential it is to rely on your team's strengths to succeed.

In terms of leadership, I realized that my style is more collaborative than authoritative. I prefer working alongside others, contributing where I can, and ensuring the team is aligned in terms of goals. However, I also learned that leadership sometimes means stepping up and making decisions when there's no time to deliberate endlessly.

There were moments in the project when things weren't going as planned, and taking charge of troubleshooting helped move things forward faster.

Looking back, my biggest asset to the team was my ability to bridge the technical and creative aspects of the project. My experience coding and integrating hardware with interactive software allowed me to contribute meaningfully to various stages of development, but it was also important that I could think from the perspective of the user—especially the kids at the Beachmont Expo. I kept their experience in mind, ensuring the game wasn't just functional but engaging and educational.

If I could go back to the beginning, I would focus more on refining our testing and iteration phases earlier in the process. While we eventually got everything working, I think we could have avoided some of the stress by establishing a more thorough testing protocol before we reached the final stages. If we had more time, I would have loved to add more interactive elements to the display, like real-time progress tracking or a deeper educational layer that could provide more context for the children about how the temperature game was simulating a scientific process.

This project has definitely changed how I approach both teamwork and technical challenges. It reinforced the value of working with others who bring different strengths to the table, and how flexibility and clear communication can make or break a project. From a technical standpoint, I've grown in my understanding of hardware-software integration, and I feel more confident in my ability to troubleshoot and adapt in real-time. The experience working with children also reminded me of the importance of keeping the end-user in mind—something I'll carry with me into all future projects.

JOSEPH AFFLITTO

19 DISCUSSION

Overall, the design succeeded in implementing the various techniques and elements we had initially planned. The inclusion of these aspects had an overall positive effect on the users, as demonstrated by the results. Users were intrigued by the physical elements of the display and cited their moments of direct interaction as being the most engaging and enjoyable parts of the game. Users were most likely to remember information related to preferred waste types and conversion conditions, both of which were featured in the exhibit's hands-on activities.

This demonstrates that the design's elements were successful in hooking the user's attention and effectively providing access to digestible, accurate information.

19.1 PHYSICAL AND FISCAL REQUIREMENTS

The final exhibit design fits comfortably on the table dimensions and was easily transportable to the multiple locations with no major damage or difficulties. The design also limited dangerous elements for students, which prevented potential injuries or issues when being interacted with by users.

The fiscal budget of $100 was met comfortably, with the total cost for materials being visible in the Bill of Materials shown in Appendix L.

19.2 EDUCATIONAL GOALS

The exhibit had the intention of creating an educational experience that offered novel information for the users. It utilized multiple techniques to increase educational impact, mostly the use of productive-failure and interactive gameplay.

We collected data on this goal through a brief set of questions on the biogas process following the exhibit and the collection of user interaction data directly from the games. In the first game, the number of buckets successfully filled will serve as an indirect measure of understanding waste categorization and properties. In the second game, success rates will reflect the user's grasp of the necessary conditions for biogas conversion.

These metrics indicated that students were able to quickly adapt from mistakes, in turn learning the intended information and retaining it for a longer period of time. The waste collection statistics showed users were able to differentiate between waste types and understand the required qualities that must be fulfilled with biogas conversion. All the users were able to reiterate information back to the exhibit attendants, demonstrating retained information and a general understanding of the information we provided.

19.3 STUDENT ENJOYMENT

The exhibit also had the intention of acting as an enjoyable exercise for the users. To measure this metric, we included a post-interaction questionnaire. As an incentive, a small prize will be offered upon completion.

Students, overall, found the exhibit fun and interesting. Their feedback indicated the hands-on elements offered an interesting visual that enticed users to engage with the exhibit. The users demonstrated interest in the video explanations despite a removal from active participation, likely credited to the fast pace editing and interlaced humor. The games offered enough space for collaboration, allowing multiple users to interact at a given time and share an experience with the exhibit. The added physical movements required for the temperature and crank parts of the design was particularly popular, likely due to its divergence from many of the other types of exhibits and the opportunity to be active and expressive in the completion of the goal. These results indicate a success in designing an exhibit targeted to the interests of users in the younger demographic.

20 CONCLUSION

The exhibit successfully met the primary objectives of creating an engaging, educational, and enjoyable experience for young learners. Through a thoughtful combination of hands-on interactivity, clear visual aids, and elements of gamification, the design effectively captured students' attention and deepened their understanding of biogas technology and sustainability concepts.

The exhibit's structure allowed for easy transport and handling, aligning well with the physical and fiscal requirements. With the budget constraints in mind, we managed to construct a durable, safe, and functional exhibit that met all the necessary criteria. Furthermore, the exhibit's design was carefully optimized to ensure that it was not only interactive but also safe, minimizing any potential hazards for users.

From an educational perspective, the integration of productive failure-based learning and interactive gameplay demonstrated clear success. The collected data showed that students were able to grasp complex biogas concepts through active participation, indicating that the exhibit's approach to education was effective. The games, in particular, served as practical tools to reinforce knowledge retention and foster understanding of sustainability practices.

Moreover, student enjoyment was a key element of our design, and the results from post-interaction surveys confirmed that the exhibit succeeded in keeping students entertained while they learned. The hands-on nature of the exhibit, combined with an element of competition and rewards, proved to be highly motivating, ensuring that students were engaged throughout their experience.

In summary, the exhibit not only fulfilled its educational goals but also provided a fun, memorable experience that helped young learners connect with sustainability in a tangible and accessible way. Moving forward, the success of this project highlights the importance of blending educational theory with creative design to make complex topics both enjoyable and impactful for younger audiences.

21 RECOMMENDATIONS

21.1 ENHANCED USER INSTRUCTIONS AND INTERACTIVITY

User feedback indicated confusion regarding button clarity and LED signaling during interactions. To address this, clearer and more visible instructions were integrated through digital displays, such as video tutorials, along with enhanced button designs. Visual feedback—such as flashing lights—was also implemented to alert users when mistakes were made, providing guidance on how to engage correctly. These improvements reduced user confusion and contributed to a smoother, more enjoyable learning experience.

21.2 DURABILITY AND STRUCTURAL REINFORCEMENT

The exhibit faced durability issues during transport, with some components becoming unstable. To address this, the structural supports were reinforced, and the base design was updated to improve stability. Modular panels were also incorporated to allow for easier assembly and disassembly, reducing the risk of damage. These improvements enhanced the exhibit's durability and reliability during transit and use, ultimately increasing its longevity and effectiveness in various settings.

21.3 REFINING GAME MECHANICS FOR CLARITY AND LEARNING

To improve the educational impact of the interactive games, several refinements were made to better align game elements with key biogas concepts. While user interaction data indicated strong engagement, it also revealed areas where understanding—particularly around waste categorization—could be strengthened through more thoughtful design. The interaction steps were simplified, and additional feedback loops were incorporated to provide users with clearer indicators of success or failure, reinforcing the intended learning outcomes. These changes were intended to enhance concept retention by offering immediate and intuitive feedback. Visual enhancements were integrated into the updated game design and tested with students to assess their effectiveness. Additionally, modular components were developed to incorporate topics like solar or wind energy, making the exhibit more adaptable and capable of addressing a broader range of educational goals. Together, these improvements created a more comprehensive and impactful learning experience for diverse audiences.

22 LESSONS LEARNED

22.1 CONTRIBUTIONS

Between Milestones 5 and 7, I was heavily involved in refining and finalizing the physical design and integration of the exhibit. My primary contributions centered around the structural hardware and how all the interactive components came together into one cohesive system. I finalized the design of the main panels, ensuring they were modular, structurally sound, and adaptable for the mounting of various game mechanisms. This included planning for precise cutouts, wire management, and future component integration, especially where motors and electronic elements would be embedded.

I also created and implemented the tubing paths that serve as visual and functional elements for the exhibit, as well as the housings for the atomizer, crank, and LED strip systems. These additions required not only technical planning but also a creative mindset to ensure they contributed to the exhibit's thematic appeal. Using AutoCAD, I designed all the custom structural components and managed the laser cutting of those pieces—ensuring accuracy, fit, and visual consistency across the entire exhibit. Every piece that was laser cut was directly tied to models I built in CAD, which helped streamline the physical build process and avoid unnecessary errors during assembly.

Beyond just the physical design, I played a key role in unifying the various contributions from my teammates. As their specialized features were completed, I made sure they were structurally supported and positioned in ways that felt natural and engaging for users. I consistently helped tie the work of all team members into a single, coherent product, helping guide decisions so that the exhibit functioned smoothly as a whole. I also worked closely with our project mentor during this phase, taking in their feedback to maintain our creative ambitions while still managing our workload. These combined contributions prove that I was deeply involved in both the practical and conceptual development of the final product.

22.2 RESOURCES

Our group comfortably met the defined budget for the project, as documented in the final budget summary provided in Appendix L. Personally, I contributed a number of key components to ensure the exhibit functioned as intended. This included acquiring an iPad screen, an Arduino Redboard, various smaller Arduino components such as LEDs and servo motors, arcade buttons, and the bolts used to secure the panels to the base. In terms of time commitment, I devoted over 30 hours a week throughout the six-week span of the project, with the majority of that time focused on physical design, construction, and Arduino integration. This intensive involvement taught me a great deal about resource management—particularly how to better balance time between academic responsibilities and major project commitments. With such a large workload, I was forced to reevaluate how I prioritized my time, which ultimately improved my ability to manage multiple tasks efficiently. This experience has made me more intentional in how I plan and allocate both financial and personal resources, which will benefit me in future engineering endeavors.

22.3 REFLECTIONS ON LEARNING

This project has pushed me to understand my own capabilities in learning, adapting, and overcoming challenges, while offering an experience that closely mirrors a genuine engineering work environment. Having so much freedom to tackle problems was entirely new to me, and it added both complexity and fulfillment to the process. It encouraged me to think independently, make real-time design decisions, and take full ownership of my work in a way that felt both meaningful and professionally relevant. Along the way, I had to teach myself essential technical skills—most notably CAD design and elementary programming. I am especially proud of the CAD skills I developed, as they allowed me to transform abstract ideas into precise, laser-cut components, directly linking creativity to tangible engineering outcomes. Beyond these hands-on skills, the project gave me a deeper understanding of the engineering process itself, from ideation and prototyping to integration and final testing. This experience helped me grow not only as a designer and builder, but also as a team member capable of navigating complex challenges—an invaluable foundation for my future career in engineering.

22.4 REFLECTIONS ON EDP

A critical takeaway from this project has been the importance of clearly defining problems before attempting to solve them. Understanding a problem is one of the most essential steps in the engineering process, and I plan to implement effective problem definition by breaking complex challenges into smaller, manageable parts and identifying the root causes. This method not only clarifies the constraints and requirements but also allows for more targeted and efficient problem-solving strategies. I've also grown more confident in solution generation, thanks to structured techniques like the 3-5-3 method and storyboarding. These strategies helped guide creative thinking within purposeful boundaries, making it easier to explore innovative ideas while staying aligned with project goals.

When it comes to communicating future decisions, I believe I'm in a strong position to do so effectively. Tools like the Kepner-Tregoe decision analysis have made it easier to compare ideas objectively, giving weight to discussions and offering a clear rationale behind each choice. This structure adds credibility to decision-making and allows others to understand not just what was decided, but why. Looking ahead to future projects, I aim to improve implementation by developing more detailed timelines and progress check-ins to catch issues earlier and avoid last-minute adjustments. Better organization during the implementation phase will also help distribute tasks more evenly and prevent burnout.

To make future evaluations more robust and foundationally sound, I plan to incorporate a more data-driven approach, using both qualitative and quantitative feedback to assess outcomes. This includes setting clear success metrics early on, using structured surveys, and collecting observational data to measure engagement and understanding. By embedding evaluation into the design process from the start, rather than treating it as an afterthought, I can ensure that future projects are not only well-executed but continuously improved through meaningful reflection and evidence-based iteration.

22.5 REFLECTIONS ON WORKING IN A TEAM

This project had a major impact on how I function within a team and deepened my understanding of effective collaboration. One of the biggest changes in my team-working skills was learning how to balance initiative with support—knowing when to take charge and when to step back and help others. I became more comfortable sharing ideas openly, listening actively, and bridging the gaps between different parts of the project. A challenge we had to overcome was integrating very different ideas and technical skills into a cohesive final product. It forced us to communicate more clearly, compromise when needed, and trust each other's areas of expertise. While our teamwork strengthened throughout the project, one area I still want to improve is how I delegate tasks. I tend to take on too much at once, and I'm learning that effective teamwork means trusting others with responsibility.

In terms of leadership, I naturally gravitate toward a collaborative style. I like to guide by example, contribute consistently, and help tie ideas together so the project remains focused. At the same time, I feel that I'm very manageable as a team member. I respond well to clear direction, constructive feedback, and structured goals. When we encountered adversity—like mechanical failures, coding delays, or design disagreements—we tackled them as a team by refocusing on the big picture and dividing up the work in a way that played to everyone's strengths. My biggest asset to the team was my ability to visualize the full scope of the exhibit and bring cohesion to the project, both in terms of physical design and conceptual flow.

If I could go back to the beginning of the semester, I would've pushed for earlier integration of all components. We often waited too long to combine hardware and software elements, which caused some unnecessary last-minute stress. If we had more time, I would've loved to expand on the visual and interactive elements—adding more animated graphics, polishing the LED sequences, and improving the aesthetic details to enhance the museum experience. Overall, the project was a huge learning experience, not just in engineering and design, but in how to work as part of a dedicated, creative team.

EVA MESCHER

23 DISCUSSION

Our exhibit design met all of the functional requirements we laid out in our problem statement. It met all size, budget, and transportation requirements. It also met the main objectives outlined in our problem statement, including being engaging, challenging, and educational for the students.

23.1 EASILY MEASURED GOALS AND REQUIREMNTS

Our exhibit was within the size requirements mentioned previously. It fit easily on the table provided and was easy to transport between locations in the bag provided. The set up and break down was less than 15 minutes. It was also light enough that each person in our group would carry it themselves. After the first expo of the day it continued to function even after transportation proving its durability. Further, there were no sharp edges that could potentially injure the kids, allowing them to engage in a fun and safe way. Further, the cost of our exhibit was well under the $100 budget. Our budget log can be seen in appendix L.

23.2 USER ENGAGEMENT

Many different users, from adults to children, to peers played our exhibit, and all appeared to enjoy and engage with our exhibit. They were able to complete the tasks without our direction and use the educational videos to learn and understand the task at hand. An initial concern we had was that users might get bored and decide to leave halfway through our game. This, however, was certainly not the case, and all players finished all three parts of our game. Utilizing push buttons to allow the user to control different aspects of the game helped engage them. Giving them control to compete and try their best motivated them to play and engage with our exhibit. Many of the kids, especially, were excited by the competitive nature of the game. We also utilized audio and monitor graphics to engage our users. The sounds effects after the collection of a piece of waste helped give cues to the players on how well they were doing. This feedback, like in any game, is so important to engaging players. The audio for our educational videos also attracted people to our game and excited them to want to play. I also noticed at Beachmont that some of the shyer kids liked to watch their friends play first. This along with the option to play with a partner, helped them gain confidence to try the game.

After playing we got a ton of positive feedback from people saying that they really enjoyed playing. Some of the kids even came back to play a second time. We also asked the kids what their favorite part of the exhibit was, and the majority replied with our temperature crank game. I think this one was popular because of its physical elements. They got very excited about the crank and tried to turn it as fast as they could. Overall, the physical elements paired with the visual graphics and audio feedback helped engage our users and bring out their competitive side.

23.3 EDUCATIONAL GOALS

Our main educational goal for our exhibit was that the users would learn about the basic process of biogas and the different types of waste that can be used. We structured our compost collection game so that to be successful, the users had to learn the “good” and “bad” types of waste that could be used. After each collection of waste, a “success” or “failure” sound was played. This gave the kids feedback and helped them learn. We chose sounds that the kids might recognize from other games. We noticed that the adults didn’t always pay attention to the video and struggled to differentiate between the good and bad waste. However, the kids were able to quickly learn and realize that the “bad” sound corresponded to waste that cannot be used in biogas production. On average the adults and our peers collected around 3 buckets of waste while the kids averaged 3.75 buckets. We changed the percentage of good to bad waste for the kids because we noticed some of the adults getting frustrated when they randomly got a run of bad waste. However, watching the kids play, you could tell from their facial expressions, reactions, and actions that they were quickly learning what was good vs bad waste.

After completing the game, the kids earned a little poop as a prize. Some of the kids kept coming back because they wanted more of these poops. To earn another poop, they had to correctly answer some of our questions. We quizzed them on types of waste and the processes that occur in biogas, and many of them were able to correctly answer, showing learning and an understanding of the concept.

Overall, this showed some level of learning retention. From the beginning, they learned about biogas through our educational videos. Then they had to apply this knowledge to the game to be successful. Then finally, many of them showed understanding through the answering of quiz-like questions.

24 CONCLUSION

Problem:

Currently, in many schools, sustainability is not taught in such a way that sparks interest among students. We were provided with the task of creating a sustainability-focused museum exhibit for elementary and middle school students with the goal of engagement and long term-retention. We aimed to create an exhibit that was interactive, educational, and accessible, especially for students from under-resourced backgrounds. Education today focuses on a more passive form of learning, so our challenge was to give the students the opportunity to engage in such a way that is not only fun but allows them to actively learn. To do so we focused on creating a design that was focused on a physical and tactile layout which allowed us to use a story-driven narrative and create a fun and motivating environment.

Developed solution:

We built a Biogas exhibit that uses humor, storytelling, and hands-on interaction to teach kids how waste can become energy. Our first main game was our compost collection game where students had to decide which waste could and could not be used in biogas creation. Our second game showed the conversion process and two of the necessary requirements: temperature and consistent mixing. Finally, we finished by showing one potential application and use for biogas. We showed how the biogas they made could be used to power a tractor and save the chickens. For these different games we utilized buttons, and servo motors to show live motion in bucket collection as well as temperature control. We also used an encoder to track the number of cranks made by the students. To create a falling effect of the waste we utilized LED strips. All of these components were controlled by Arduino and its communication to MATLAB. To set the students up for success and to teach them, we utilized our iPad monitor to show educational videos before each game. During each game, the monitor was used as a GUI to keep the students engaged and show various information and player status. To create the physical structure, we laser cut wood. We constructed four sections which included the three in the trifold along with the base. This allowed for easy transport and set-up.

Address the given problem:

We focused on catering to the interests of the kids rather than the interests of adults. We related to the kids with bathroom humor and poop, which the kids loved. Our exhibit allowed the kids to play and be challenged while still learning. We designed our exhibit so that to be highly successful the kids had to learn about various aspects of biogas. Our open design allowed the kids to preview beforehand and help them gain confidence to engage. Our story narrative also helped the experience feel more realistic, which helped make that connection to the real-life benefits and applications of biogas.

Design Process:

To create a solution for this problem we utilized the engineering design process. This allowed us to start off by researching and figuring out what needed to be included to create a successful design. This helped us prioritize and figure out what would make a truly fun, engaging, accessible, educational, and interactive experience for kids. This also allowed us to target and focus on the needs of the kids. This initial step of defining the problem was helpful to creating a base to work off. The next step of generating ideas and solutions helped keep a wide variety of options. Instead of narrowing down our options we were able to fully explore the solution space and create many good possible solutions. The next step of deciding on a solution helped us pick the best solution in the most objective way possible. We used many of the criteria we set from our first step of problem definition along with a decision matrix to make this decision. The next step of implementation allowed us to further refine a cohesive idea and construct a working prototype. Building a cardboard prototype also proved to be extremely helpful because it allowed us to visualize our idea in physical space rather than just on a screen and make changes where necessary. Finally, we evaluated how our prototype performed with user interactions. To do this our prototype tracked data, and we asked the users questions after they completed the exhibit. Taking all these steps proved to be far more productive than jumping straight into constructing and building.

Impacts:
The hope for this project is that it allows students who might not usually have access, to learn about sustainability and various STEAM topics. We want to build curiosity in the students and maybe even a passion or interest in the subject.

25 RECOMMENDATIONS

Based on feedback received from peers, adults, and the students there are a few changes and improvements I think would help increase user engagement, learning retention, and better the overall experience.

25.1 IMPROVED INSTRUCTIONS

Based on peer feedback and game play results, instructions and general information on biogas could be clearer. Our instructional video played a little too quickly, and I think some users might have gotten distracted and might not have taken in or understood all the information. To improve this, I would lengthen the video and maybe add quick quiz questions to ensure they were listening. If they fail to answer these then that short section could be replayed for them so that they can re-learn it and successfully answer the question. Another issue noticed during game play, was that some of our graphics and audio sounds lagged a little. For the next iteration of the design, I would alter the code to try and reduce this lag. Editing some of the audio clips would also help improve this.

Another issue noticed during user play was the disconnect between the monitor graphics and the buttons. I think visually the monitor graphics could be improved to highlight the waste being dropped and the bucket status. I think these were often overlooked initially, and had they been clearer I think it would have helped minimize initial confusion and helped foster more learning.

Another improvement I would make is changing how the buttons light up to minimize confusion. We had the buttons turn on when they were ready to be used, but in certain cases it might have been more helpful to make the button blink before use. Then while in use only have it on and a solid color.

Another improvement I would make to minimize confusion is adding more audio cues and feedback. I think this helped with the compost collection game and could be expanded to use in other areas of the exhibit. For example, adding audio to the temperature game to help show progress would have helped make it clearer the learning objectives. Adding audio to the tractor portion would have helped make it even more realistic feeling and engaging.

25.2 CHECK FOR UNDERSTANDING

After the completion of the game, we asked users about their experience and tried to gauge how much they learned. However, I think we could vastly improve this and create a quiz-like recap section at the end. The kids could be shown a little recap slide or video and then answer three to five short quiz questions to check for understanding. Even if the kids can easily answer all questions, having this last check-in to revisit information is extremely important for long term learning retention. Following this, having some sort of leader board shown at the beginning and the end would urge kids to compete and try their best to learn. Hopefully it will result in more engagement and higher learning retention rates.

25.3 IMPROVED STRUCTURAL DESIGN

The basic design of our exhibit, I believe, was very effective in creating an inviting atmosphere for the kids. However, there are a few changes I would make to further improve the design. If given more time, I would redesign the side panels to close the gap between the middle and the side. This would be more visually appealing and look even more professional. I would also improve the tubing on the right panel. Between tubes, there were gaps that would look cleaner if closed. Further, I would try to change some of the graphics to make clearer the purpose of the digestor being connected to the collector tank. Adding labels and updating some of these graphics would go a long way.

To make this piece look even more professional, I would close off the back of the panels, so that no electronics could be seen from behind. For a long-term solution I would also put in a permanent monitor and run the code instead from a Raspberry Pi or online server. This would eliminate the need for an external computer to control the game. All these components could be housed within the exhibit, eliminating the need to have external devices or cords running throughout.

26 LESSONS LEARNED

26.1 CONTRIBUTIONS

In milestones five to seven I contributed to the coding and design of the compost collection game. I also worked on different aspects of the temperature crank game as well as the tractor motion. I also helped cut down the wood to be laser cut, redesign the base plate and created AutoCAD drawings, and helped construct the physical pieces. To combine everything into one cohesive exhibit, I created the MATLAB code to integrate these different parts. I also painted the middle monitor section and decorated the LED strips.

Compost Collection Game:

I worked on the LED strips and coding for the compost collection game. I programmed the LED strips to look like they were falling and cut them into four strips and soldered them together. I also soldered longer wires to the buttons to be able to connect them to the red board more easily. I designed the basket collection mechanism. We were struggling to figure out how to create linear motion from a rotational servo motor. I designed a three-part piece that would give the basket an additional two degrees of freedom to be able to move in a straight line and stay horizontal the entire time. A drawing of this design can be seen in appendix E. I also designed a piece to hold the servo motor in place, which can be seen in appendix E. I also worked on the code for this servo motor to allow the user to move it left and right using the buttons. Initially, it wasn't possible to allow the LED lights and servo to be on the same Arduino board due to timing issues, so we put them on separate boards. To connect them I learned how to do serial port communication and integrated the code into MATLAB. The Arduino code for the servo motor and LED strips can be seen in appendix G, along with the MATLAB code. The MATLAB code calls for a randomized type of waste and which strip to fall down. It also signals to Arduino to start the servo code. With both working, I programmed the servo code to return an angle number which could correspond to a certain strip. This allowed us to check if the waste was collected. This made the base for the compost collection game. From here along with some help from a teammate, I gathered separate images of all the different types of waste. This allowed me to create a GUI where the type of waste popped up above the LED strip before the lights "fell" down. I created this by overlaying png images into a plot in MATLAB. An example of this screen can be seen in appendix J. I also drew three different bucket graphics that were empty, 1/3, 2/3, and completely full. This allowed me to show the users their progress as they collected waste. If they collected a "good" piece of waste the bucket would increase by 1/3 (a new image would overlay). If they collected a bad piece of waste, the bucket would empty (the empty bucket image would show). These different images allowed the illusion of the bucket filling up. All of the bucket pictures and waste icons can be seen in appendix J. I also designed the MATLAB code so that a tally in the top left would show the number of filled buckets.

Temperature Crank Game:

For the temperature crank game, I used the Arduino code programmed by a teammate and integrated it into the serial communication system. I helped edit the code so that it worked better in the system and added to the MATLAB code which told it when to run. For this game I also designed a temperature needle to attach to the servo that can be seen in appendix E. Further to integrate this game into the monitor I drew a stop motion-like series of png pictures that gave the illusion of gas rising and collecting in the tank. One of my teammates combined the picture in a video which I integrated into the MATLAB code. I programmed it so that the video would only play if the temperature servo was within the correct angle range and the number of cranks was increasing. If one of these wasn't true, the animation would pause, and no biogas would be created.

Tractor Mechanics:

For the tractor part of our exhibit, I edited the tractor servo code and integrated it into both the Arduino and MATLAB code. When the tractor button was pressed (and the temperature game was finished), the tractor would move to the ends towards the chickens. It would then reset itself when the game was finished. We were having some issues with the tractor movement because we weren't able to position the servo at the correct distance corresponding to the slot cutout radius. To combat this, I designed a piece that minimized this binding affect by creating another degree of freedom. This design can be seen in appendix E. For all the servos we used, I designed a piece that connected to the servo on one end and a wooden dowel on the other. This can be seen in appendix E.

MATLAB and Monitor Integration:

To allow our exhibit to run smoothly and rest itself, I created the MATLAB code that controlled the Arduino boards. To start the exhibit one of the middle buttons lit up blue and showed a screen to tell the user to press the button to start. After helping edit the first instructional video made by my teammate, I added this into the code so that it would play right after the button was pressed. I also had to add in and change the timing of the audio separately because MATLAB doesn't play audio with videos. After the video finished, the compost collection game would start. I programmed it so that the two middle buttons would light up signifying which ones to use. For this game I added two different audio sounds that would signify whether the waste collected was good or bad to give the user feedback. After this game finished, I showed a picture of the number of buckets collected on the screen so that the user could see their progresss. After this I programmed it so that it went into the second instructional video. Following this video, the temperature game started, and the corresponding button LED turned on. After the completion of this game, I displayed the image of the tractor instructions and lit up the corresponding tractor button. Once the chickens were saved, I played a celebratory audio clip. I also included code to write different variable values to evaluate how well the users did. The MATLAB code was on an infinite loop so after this, the whole game reset and was ready for the next player.

26.2 RESOURCES

Our group was well under the budget, and the breakdown of our expenditure can be seen in appendix L. I bought the laser cutting wood from Home Depot for our project. I devoted a large portion of my time outside of class and even outside of group meetings into this project. This amounted to around 105 hours, which can be seen in appendix M. I think tracking our resources proved to be very helpful because we were very conscious of our spending. Although the wood from Home Depot was farther away, it was far more cheaper than the wood from Northeastern. This project helped me realize how much you can do with a small budget. It also helped me realize the importance of using sustainable materials and materials that can be re-used or recycled. We borrowed many components from FYELIC that are now still able to be used by students in the future.

26.3 REFLECTIONS ON LEARNING

I think this project helped me learn how effectiveness the engineering design process is. I think this process really helped me see the value in the earlier steps like problem definition.

Using MATLAB in communication with Arduino was very new to me. I didn't originally know this was possible nor know how to do it. This is something I had to teach myself and figure out. This helped me get better at finding my own resources and using them to solve a problem. This is a skill that I am proud to possess.

I don't think there is any specific piece of information that will necessarily benefit me in my career, but I think the process as a whole was incredibly beneficial for me and my future career. There were so many things I learned along the way and skills that I improved on which will definitely benefit me in the future.

26.4 REFLECTIONS ON EDP

Using the engineering design process was a lot more effective than I initially anticipated it would be. The first step of problem definition really helped us create a set of priorities which guided many of our decisions throughout the process. In the future I would implement this step by focusing on the audience (through empathy maps, research, etc.) to create a problem statement geared towards their needs and wants.

I think this project helped me learn many new ways of solution generation and how important it is to create a wide range of different ideas. I feel very comfortable with this step because I like to think about how different ideas could be implemented and brainstorm a variety of solutions.

I think this project and process helped me get better at communicating different decisions. Sometimes this step can be challenging because deciding on a solution can be very subjective. Using the Kepner Tregoe decision matrix was very helpful because it helped us make a decision in a more objective manner. I think this process helped me improve my communication skills regarding communication.

For future implementations I will try to plan out the design better. We made some mistakes in our initial plans and had to change them, which cost us time and resources. In the future I would spend more time planning so that the implementation phase goes smoother.

In the future I would add a more automated evaluation system. As mentioned previously, I would incorporate in a mini quiz at the end of the game to see how much the kids learned. I would also add a rating scale by using markers like stickers to get the kids feedback on their enjoyment. This would help give us more quantitative data that could be further analyzed.

26.5 REFLECTIONS ON WORKING IN A TEAM

I think this project helped me grow and get better at my communication skills. It helped me change from a more passive role to a more active role in the group. In the past I had always done my work and communicated with my group mates, but I didn't always take the initiative to make decisions or reach out. This project really pushed me to be more vocal and lead a little more than I was used to. Communicating with my group and taking the initiative, especially in the beginning, was a challenge for me. However, as the semester progressed, I improved and started to take more initiative to help us plan and stay on track.

One aspect of teamwork that I still need to work on is my acceptance of alternative ideas. I am very much a perfectionist, and I try to spot all the potential flaws in an idea. Sometimes this is unnecessary and can slow down progress, so it is something that I have been working on this semester and will continue to work on in the future.

My leadership style is more lead by example. However, this semester I have gotten better at leading and being more vocal. I also think my ability to be managed is fairly good. When my groupmates were project managers, I always made sure to complete the task by the target dates they had set. I also made sure to communicate my progress to try and make their job easier.

We had a lot of different components in our exhibit, and the biggest thing we were up against was the clock. To overcome this, we focused on prioritizing the essential parts of the exhibit and getting to the others afterwards. We also planned and set deadlines for different components to try and stay on track and complete the exhibit in time.

I think my biggest asset to the team was my ability to think critically and come up with fixes for various issues we were experiencing. When we were having trouble with tractor mechanics or the basket design, I brainstormed potential solutions to try and combat these issues. I also advocated for these fixes when others didn't have complete faith.

If I were to go back to the beginning of the semester, I would have tried to frontload the work a little more. I think we could have made more detailed plans and designs in the earlier milestones, which would have helped us be more efficient while building later on. We still made it work, but I think it definitely would have helped to balance out the workload had we done this. I would also try to add a fun quiz for the kids at the end. This would help with long-term retention. I also think I would change the way the different games were connected. I think we could have put more emphasis on how the actions the kids took helped create biogas. We did this to an extent, but I think it could have been more impactful if we had a way to show different amounts of biogas production based on how well the kids did. This could allow for a leaderboard at the end, which would create some fun competition.

CAROLINE DIMAIO

27 DISCUSSION

Our exhibit fully met the specified size and design requirements, ensuring it fit seamlessly within the designated space and adhered to all structural guidelines. Beyond meeting these technical standards, it also accomplished its primary goal of creating an effective, engaging, and educational museum experience tailored specifically for children. Through interactive elements, age-appropriate content, and thoughtful design choices, the exhibit provided a meaningful learning environment.

27.1 EASILY MEASURED GOALS AND REQUIREMENTS

The exhibit adhered well to the required size constraints and fit comfortably on the exhibit table. Its modular design allowed it to be easily deconstructed, stored in the designated transport bag, and carried efficiently by any team member. Careful attention was given to safety, with no sharp edges or inappropriate content ensuring a safe and effective educational experience for children. Additionally, the entire project was completed within the $100 budget, with a detailed cost breakdown provided in Appendix L.

27.2 EDUCATIONAL VALUE

Our group placed a strong emphasis on how we could effectively educate students while keeping the experience engaging and memorable Through collaborative discussions and thorough research, we identified bold visuals, vibrant colors, and gamification as key strategies to capture attention and reinforce learning. The exhibit introduced students to the concept of biogas – what it is and how it's produced – through short, entertaining, and informative videos. To further solidify their understanding, we incorporated interactive games that challenged their attention and tested their knowledge in a fun and dynamic way. The students demonstrated strong engagement and retention, which became evident through their correct responses to follow-up questions at the end of the exhibit – motivated, of course, by the chance to win another take-home poop toy.

27.3 USER SATISFACTION

User satisfaction was evaluated through follow-up questions presented at the end of the exhibit. These questions included:

1. *Did you have fun? If not, what didn't you like about the experience?*
2. *What was your favorite part?*

We were pleased to find that every student responded "yes" to the first question, indicating they had fun. Their enthusiasm was further confirmed by the number of students who returned for a second round of gameplay, showing strong engagement and interest.

For the second question, the majority of students identified the third section of the exhibit – the temperature game where they made biogas – as their favorite. This section stood out due to its interactive elements: students used a hand crank and temperature button to simulate the process of biogas production. The visual feedback enhanced the experience – cold air emitted from a humidifier represented the gas, while a monitor displayed a virtual tank filling with biogas.

An additional highlight was the two-player format of the game, which encouraged collaboration and peer learning.

This social aspect of the experience aligned with our research on effective learning environments and contributed to a fun, yet educational, atmosphere that resonated with the students.

28 CONCLUSION

During our visit to the Museum of Science, we observed that many current exhibits lacked visual excitement, were overly content-heavy, and failed to deliver an engaging or effective learning experience – especially for younger audiences. While delivering educational content is essential, our team recognized the critical importance of designing with the user in mind. In our case, that meant tailoring the experience for elementary and middle school students.

28.1 DEVELOPED SOLUTION

To ensure our exhibit truly connected with this age group, we conducted research on how children are drawn to, engage with, and retain information. Key findings emphasized the value of gamification, bold color schemes, fun and relatable narratives, and age-appropriate language as crucial components of a successful educational experience.

Guided by these insights, we developed a vibrant, farm-themed exhibit complete with bright visuals, engaging photos, 3-D printed elements like tractors and a chicken coop, and a storyline that carried throughout the experience. To make complex information more accessible, content was delivered through short, visually dynamic videos that incorporated playful fonts, upbeat music, and animation.

The educational journey was broken down into three interactive sections: learning what biogas is, collecting compost to start the process, and heating/stirring the waste to produce biogas. The narrative concluded with a high-stakes challenge where children used the biogas they created to save chickens in an “emergency” scenario – helping them visualize not just how biogas is made, but also how it can be used in real life.

Another insight from our research was the value of take-home elements to reinforce learning. To support long-term retention and add a fun final touch, students received a mini poop toy after completing the exhibit – an unexpected but highly popular reward that tied back to the learning in a playful, memorable way.

28.2 DESIGN PROCESS

The design process played a vital role in the successful development of our museum exhibit, particularly in the early stages when we were identifying the core problem and understanding the needs of our target users. Investing time in refining the technical aspects of the design was essential, as it laid the foundation for both our prototype and the final construction. Following the structured steps of the design process not only helped clarify our goals but also allowed the team to stay organized and focused throughout the progression of a complex, multi-phase project.

28.3 POTENTIAL IMPACTS

When designing a museum exhibit for children, it is essential to consider the diverse range of users who will interact with it. This includes creating a space that is accessible and welcoming to individuals of all heights, abilities, races, genders, and ethnic backgrounds. Our team was intentional in ensuring that every aspect of the exhibit was inclusive, user-friendly, and safe for all participants. We prioritized clear, approachable content and an intuitive layout, while also eliminating physical hazards – such as sharp edges – or any elements that could be perceived as exclusive, insensitive or harmful. Creating an environment where every student feels represented, respected, and engaged was a guiding principle throughout our design process.

29 RECOMMENDATIONS

This section outlines key recommendations for improving the design, assuming additional time, resources, and advance notice were available.

29.1 VISUAL ELEMENTS

Given more time, the visual elements of the exhibit could be significantly enhanced. While the overall message and narrative were effectively conveyed, the quality and execution of certain visual components left room for improvement. Initially, physical images were mod-podged onto the panels; however, this method resulted in air bubbles and an uneven, low-quality finish. In a last-minute effort to improve the presentation, the paper was removed, and the panels were instead painted or enhanced with 3D elements, which helped create a more polished look.

Additionally, the educational videos – while engaging – had to be shortened due to timing and display limitations within MATLAB. As a result, some educational content was trimmed to ensure the videos remained concise and maintained student attention. With more time, these videos could include slightly more detail without sacrificing engagement.

Lastly, the cohesiveness of the farm-themed narrative could be further refined. While the storyline was present, the exhibit consisted of multiple interactive sections, and ensuring a smoother, more intuitive flow between them would be a key area of focus in a future redesign.

29.2 GAME DURATION

The overall duration of the exhibit proved to be somewhat lengthy, which posed a risk to maintaining student engagement. While our team took steps to address this – such as shortening the educational videos and accelerating the pace of the games – there is still room for improvement in streamlining the experience. One potential enhancement would be to find more time-efficient ways to achieve the exhibit's learning objectives. This could involve combining certain games or narrowing the focus to highlight one core aspect of biogas, allowing for a more concise and impactful experience without compromising educational value.

29.3 WORKING MECHANICS

In terms of functionality, several components of the exhibit could be improved to enhance reliability and user experience. One notable issue is the limited lifespan of the servos, which introduces a risk of mechanical failure that could disrupt gameplay and diminish the overall interactivity of the exhibit. Exploring alternative solutions - such as more durable servos or higher-torque motors – could provide greater stability and longevity.

Additionally, more time would have allowed for full implementation of the atomizer, which was intended to simulate biogas production through the release of mist. Unfortunately, due to technical challenges, the mist maker module could not be integrated in time for the exhibit. As a workaround, our team used a cold humidifier concealed behind the paneling to replicate the visual effect of gas emission. Ideally, the mist maker would be fully functional, controlled via Arduino, and synchronized with the temperature game to create a more immersive and dynamic experience. In a future iteration, these components would be housed discreetly within the tubing structure, ensuring a seamless and contained setup that enhances both realism and user engagement.

29.4 ENHANCED FEEDBACK

The feedback we received throughout the exhibit was somewhat limited. While the games provided useful data on how well players performed- indicating their level of attention and knowledge retention – they did not offer insight into overall user satisfaction. To gather that information, we manually asked participants whether they had fun and what their favorite part of the exhibit was. While helpful, this method lacked consistency and wasn't visually integrated into the experience. In future iterations, incorporating a virtual feedback system – perhaps through an interactive screen or digital prompt at the end – could enhance both the visual aesthetics and data collection process providing more structured and engaging feedback from users.

30 LESSONS LEARNED

Serving as both a team member and project manager was an incredibly valuable learning experience. It allowed me to gain deeper insight into my own strengths, time management skills, and capabilities. More importantly, it taught me how to effectively communicate and collaborate with others. Since the success of the project depended on each team member fulfilling their responsibilities, it was crucial to develop clear and respectful communication strategies. I learned how to balance accountability with empathy, maintain a positive and motivating attitude, and support the team in staying aligned with our shared goals. This experience not only strengthened my leadership skills but also highlighted the importance of fostering a collaborative and encouraging team environment.

30.1 CONTRIBUTIONS

During milestones 5 and 7, I focused the majority of my time and effort on the visual and educational components of the exhibit. My primary goal was to translate a complex sustainability topic-biogas-into a format that was both accessible and enjoyable for children of varying ages and learning styles. To do this, I researched and developed age-appropriate language and educational content that maintained a playful, lighthearted tone while still conveying key scientific concepts.

Building on this foundation, I created three original educational videos, each designed to engage young audiences through bold visuals, bright colors, fun transitions, sound effects, and a clear narrative. The first video introduced biogas, explaining what it is and how it's used in an age-appropriate and engaging way. The second was an instructional video for the compost collection game, offering simple, clear directions and explaining the purpose behind the activity. The third video guided users through the temperature game, detailing gameplay mechanics and helping them understand what to expect as they simulated the biogas creation process.

To strengthen the farm-themed storyline, I also digitally designed visuals to introduce the final "emergency" segment – where children used the biogas they created to save the farm's chickens. On the physical side, I spent considerable time designing and implementing a cohesive visual identity for the exhibit. This included selecting a vibrant color scheme, choosing engaging imagery, and creating graphics that complemented the narrative. Through a combination of painting, photo editing, and mod-podging materials, I brought these visual elements to life, dedicating much of my time during the final milestone to assembling and refining the exhibit's overall aesthetic.

Another key element I contributed to was implementing a visual simulation of biogas using an atomizer. Initially, I attempted to use a mist maker module controlled by Arduino to produce the gas effect. While the concept was promising, we were unable to get it functioning reliably in time for the exhibit. As a creative workaround, I devised an alternate solution using a cold humidifier fitted with a straw, concealed behind the third panel's tubing. This setup successfully mimicked the effect of gas emission, adding a dynamic and immersive visual component that enhanced the realism of the biogas production process.

30.2 RESOURCES

Our group successfully designed the exhibit well under the $100 budget, with a detailed breakdown of expenses provided in Appendix L. To help reduce costs, I contributed several personal resources, including the clear acrylic tubing used in the third panel, paint for the exhibit, physical chicken figurines for the display base and all printed visual graphics. I also provided the cold humidifier used in the biogas simulation and tissue paper to diffuse the LED lighting.

In teams of time commitment, the workload gradually increased as we progressed through the milestones. During the earlier phases – prior to physical construction- our team met 1-2 times per week, and I dedicated approximately five to ten hours per week to individual research and design work. However, starting around Milestone 4 and continuing through Milestone 7, I committed a significant amount of time each day to the project. On Tuesdays before presentations, our team often met for the entire day (from 10 a.m. to 9 p.m.) to ensure the exhibit was polished and presentation-ready.

Reflecting on the process, I recognize the importance of identifying potential problem areas and resource needs earlier in the development phase. Taking a more proactive approach could reduce the number of last-minute adjustments and alleviate much of the time pressure and stress experienced during the final stages.

30.3 REFLECTIONS ON LEARNING

Throughout this project, I gained valuable experience across multiple areas, both technical and interpersonal. One of the most significant areas of growth was in my communication and teamwork skills. Prior to this, my experience with group work was limited to short-term presentations, so participating in a long-term, collaborative project was a completely new challenge. I had to learn not only how to hold myself accountable but also how to ensure my teammates stayed on track, recognizing that we were all equally responsible for the project's success.

Over time, I became more comfortable and confident in sharing information that I might have previously considered excessive or unnecessary. I came to understand the importance of consistent communication and regular updates to ensure everyone remained aligned and informed. This shift in perspective greatly enhanced my ability to collaborate within a team environment.

Another key lesson I took from this experience was the value of maintaining a positive and supportive attitude, especially during times of stress or frustration. Despite the pressure and inevitable setbacks that came with a project of this scale, I found that encouraging and uplifting energy helped keep our team motivated and solution-focused, rather than discouraged.

On the technical side, I significantly expanded my understanding of electronics – an area in which I had limited experience beforehand, especially when it came to working with Spark Fun kits and Arduino components. While our attempt to integrate the mist maker module ultimately fell short, the process of trial and error taught me a great deal about wiring, power supply requirements, relays, transistors, and general troubleshooting techniques. I now feel far more confident in my ability to handle and work with electronic components, and I see this as a strong foundation for future hands-on projects in my academic, and post-graduate career.

30.4 REFLECTIONS ON EDP

Our team began this project with a thoughtful approach by clearly defining the core problem we aimed to solve. From the start, we understood that in order to develop an effective exhibit, each issue identified in our problem statement needed to be addressed with a well-considered solution. Throughout this process, I became increasingly confident in solution generation, as our group regularly engaged in this practice – whether it was resolving larger design challenges or quickly troubleshooting smaller technical issues.

When problems arose, we maintained open and respectful communication, which allowed us to respond efficiently as a team. Moving forward, starting the implementation phase earlier would help minimize last-minute stress and give us more time to test and refine our ideas. Additionally, to strengthen future evaluations of our exhibit, we would focus on collecting more specific, targeted feedback through carefully crafted questions – helping us better understand both user experience and educational impact.

31.5 REFLECTIONS ON WORKING WITH A TEAM

This project had a significant impact on my teamwork skills, particularly in terms of becoming more comfortable with group meetings, maintaining respectful communication, and balancing organization with a positive team dynamic. Through the course of the project, I faced and overcame personal challenges – especially with time management. Knowing that my teammates were relying on me to deliver quality work pushed me to hold myself accountable, meet deadlines, and avoid procrastination. While I've made noticeable progress in both time management and communication, I recognize there's still room for growth in these areas.

My leadership style is friendly and collaborative. As the project manager, I made a conscious effort to emphasize that I was still just one member of a four-person team. I didn't see my role as being above anyone else, but rather as a guide to help us stay on track and ensure clarity. Outside of my managerial responsibilities, I remained equally accountable for my assigned tasks. I also took the initiative to check in with teammates, offer help when needed, clarify deadlines, and keep our group focused and moving forward in a positive direction.

In terms of being managed I believe I'm easy to work with. I strive to be respectful of others' time, listen thoughtfully, and remain open to feedback. If issues or disagreements arose within the team, we addressed them directly and respectfully during meetings, which helped foster a mature and solution-focused environment.

One of my biggest contributions to the team was my creativity. I poured a great deal of effort into making sure the educational experience was not only informative but also visually engaging, cohesive, and memorable for our audience. Looking back, if i could start the semester over, I would spend more time on the implementation of visual elements rather than just the initial design. Ideally, it would have been a more balanced 50/50 split between planning and execution. Additionally, with more time, I would further enhance the visual components and expand both the quantity and quality of the educational content to create an even more impactful exhibit.

WORKS CITED

[1] “Biogas | Description, Production, Uses, & Facts | Britannica.” Accessed: Apr. 06, 2025. [Online]. Available: https://www.britannica.com/technology/biogas

[2] “Biogas, a Climate and Clean Air Solution with Many Benefits. | Climate & Clean Air Coalition.” Accessed: Apr. 06, 2025. [Online]. Available: https://www.ccacoalition.org/news/biogas-climate-and-clean-air-solution-many-benefits

[3] “EDGE: Exhibit Designs for Girls’ Engagement | Exploratorium.” Accessed: Feb. 17, 2025. [Online]. Available: https://www.exploratorium.edu/education/research-evaluation/edge

[4] G. Singh, D. K. Vatsa, S. Kaushal, Vishakha Butail, B. Kumar, and R. K. Gupta, “Development and performance evaluation of insulated biogas plant and usage potential in hilly regions,” Biomass Conversion and Biorefinery, vol. 14, no. 20, pp. 25293–25305, Sep. 2023, doi: https://doi.org/10.1007/s13399-023-04838-x.

[5] A. Getaneh, K. Eba, and G. T. Tucho, “Assessment of Biomass Energy Potential for Biogas Technology Adoption and Its Determinant Factors in Rural District of Limmu Kossa, Jimma, Ethiopia,” Energies, vol. 17, no. 9, p. 2176, May 2024, doi: https://doi.org/10.3390/en17092176.

[6]A. Nekrošius, K. Navickas, K. Venslauskas, Ž. Kadžiulienė, and V. Tilvikienė, “Assessment of energy biomass potential and greenhouse gas emissions from biogas production from perennial grasses,” Zemdirbyste-Agriculture, vol. 101, no. 3, pp. 271–278, Sep. 2014, doi: https://doi.org/10.13080/z-a.2014.101.035.

[7] Z. Q. Wang and Y. Leng, “Review of Smart Grid Demand Response with Clean Energy Access,” Applied Mechanics and Materials, vol. 446–447, pp. 847–852, Nov. 2013, doi: https://doi.org/10.4028/www.scientific.net/amm.446-447.847.

[8] Z. Hu, C. Li, Y. Cao, B. Fang, L. He, and M. Zhang, “How Smart Grid Contributes to Energy Sustainability,” Energy Procedia, vol. 61, pp. 858–861, 2014, doi: https://doi.org/10.1016/j.egypro.2014.11.982.

[9] E. Gul, G. Baldinelli, J. Wang, P. Bartocci, and T. Shamim, “Artificial intelligence based forecasting and optimization model for concentrated solar power system with thermal energy storage,” Applied Energy, vol. 382, p. 125210, Dec. 2024, doi: https://doi.org/10.1016/j.apenergy.2024.125210.

[10] Taraneh Saadati and Burak Barutcu, “Forecasting Solar Energy: Leveraging Artificial Intelligence and Machine Learning for Sustainable Energy Solutions,” Journal of Economic Surveys, Jan. 2025, doi: https://doi.org/10.1111/joes.12678.

[11] I. Nurjanah, T.-T. Chang, S.-J. You, C.-Y. Huang, and W.-Y. Sean, “Reverse osmosis integrated with renewable energy as sustainable technology: A review,” Desalination, vol. 581, p. 117590, Jul. 2024, doi: 10.1016/j.desal.2024.117590.

[12] M. A. Eltawil, Z. Zhengming, and L. Yuan, “A review of renewable energy technologies integrated with desalination systems,” Renew. Sustain. Energy Rev., vol. 13, no. 9, pp. 2245–2262, Dec. 2009, doi: 10.1016/j.rser.2009.06.011.

[13] J. F. Pierdoná Antoniolli, G. L. Grespan, and D. Rodrigues Jr., "Challenges and Recent Progress on Solid-State Batteries and Electrolytes, using Qualitative Systematic Analysis. A Short Review," ChemSusChem, vol. 17, no. 16, p. e202301808, Aug. 2024, doi: 10.1002/cssc.202301808.
[14] "10 Benefits of Solid-State Batteries: Future of Efficiency." Accessed: Feb. 18, 2025. [Online]. Available: https://renewablesadvice.com/battery/benefits-solid-state/
[15] I. Kirilova, "Specific of Personalised Learning in the Process of Knowing and Stimulating the Interests of Primary School Childern Towards the Nature," *Pedagog.-PEDAGOGY*, vol. 86, no. 6, pp. 940–950, 2014.
[16] "Knovel - kHTML Viewer," Knovel.com, 2025. https://app.knovel.com/web/view/khtml/show.v/rcid:undefined/cid:kt014010L5/viewerType:khtml//root_slug:augmenting-human-intelligence/url_slug:undefined?cid=kt014010L5&view=collapsed&zoom=1&page=5 (accessed Feb. 18, 2025).
[17] P. Backlund and M. Hendrix, "Educational games - Are they worth the effort? A literature survey of the effectiveness of serious games," 2013 5th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES), Sep. 2013, doi: https://doi.org/10.1109/vs-games.2013.6624226.
[18] N. Shaby, O. B.-Z. Assaraf, and T. Tal, "The Particular Aspects of Science Museum Exhibits That Encourage Students' Engagement," Journal of Science Education and Technology, vol. 26, no. 3, pp. 253–268, Dec. 2016, doi: https://doi.org/10.1007/s10956-016-9676-7.
[19] T. Kiriyama and M. Sato, "Design of museum exhibits and analysis of visitor-exhibit interactions," Journal of Ambient Intelligence and Smart Environments, vol. 5, no. 2, pp. 147–159, 2013, doi: https://doi.org/10.3233/ais-130197.
[20] A. S. Marcus and J. S. Kowitt, "Museum Footnotes: Helping Student Visitors Understand Museums," Journal of Museum Education, vol. 41, no. 4, pp. 353–362, Oct. 2016, doi: https://doi.org/10.1080/10598650.2016.1219584.
[21] Z. Q. Wang and Y. Leng, "Review of Smart Grid Demand Response with Clean Energy Access," Applied Mechanics and Materials, vol. 446–447, pp. 847–852, Nov. 2013, doi: https://doi.org/10.4028/www.scientific.net/amm.446-447.847.
[22] Z. Hu, C. Li, Y. Cao, B. Fang, L. He, and M. Zhang, "How Smart Grid Contributes to Energy Sustainability," Energy Procedia, vol. 61, pp. 858–861, 2014, doi: https://doi.org/10.1016/j.egypro.2014.11.982.
[23] E. Gul, G. Baldinelli, J. Wang, P. Bartocci, and T. Shamim, "Artificial intelligence based forecasting and optimization model for concentrated solar power system with thermal energy storage," Applied Energy, vol. 382, p. 125210, Dec. 2024, doi: https://doi.org/10.1016/j.apenergy.2024.125210.
[24] Taraneh Saadati and Burak Barutcu, "Forecasting Solar Energy: Leveraging Artificial Intelligence and Machine Learning for Sustainable Energy Solutions," Journal of Economic Surveys, Jan. 2025, doi: https://doi.org/10.1111/joes.12678.
[25] SHR3D.eu, Small Tractor - Flexi Excavator (Printed in One Piece Without Supports), Printables, Aug. 8, 2022. [Online]. Available: https://www.printables.com/model/233416-small-tractor-flexi-excavator-printed-in-one-piece
[26] melabam, Miniature Chicken Coop, Thingiverse, Jan. 15, 2018. [Online]. Available: https://www.thingiverse.com/thing:2758312

AUTHOR BIOGRAPHY'S

Jonathan Chan was born in East Brunswick, New Jersey, in 2006. He graduated from East Brunswick High School in 2024 and is currently pursuing a B.S. in Mechanical Engineering with a minor in Aerospace at Northeastern University in Boston, MA. During high school, Jonathan immersed himself in advanced math and physics courses, which laid the foundation for his leadership roles in both his school's competitive robotics team and business clubs. His ability to bridge technical innovation with practical application culminated in a research project on cost-efficient prosthetics, conducted in collaboration with Kean University, NJ.

In his first semester, he studied abroad in Belfast, Northern Ireland, where he explored global approaches to engineering and urban design. This experience broadened his understanding of how societal needs and cultural contexts shape the design process and reinforced his belief in engineering as a global, human-centered discipline. Jonathan would go on to explore his passion for engineering in Boston interning for Northeastern's Ferroic Atenna Lab on behalf of CoE Professor Neon Sun.

Jonathan's academic and research background continues to develop his technical skills, combining creativity and empathy to improve innovation.

Joseph Afflitto was born in Staten Island, New York, in 2006. He graduated from Staten Island Technical High School in 2024, where he developed a strong foundation in STEM and a deep interest in of chemical engineering. He is currently pursuing a B.S in Chemical Engineering with minor in Biology Sciences at Northeastern University.

During his first semester, he studied abroad at Queen's University Belfast as part of Northeastern's NU.in program, where he immersed himself in a new cultural and academic environment, further expanding his global perspective on science and engineering.

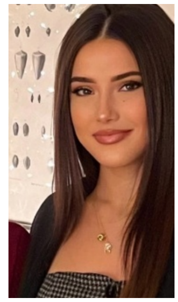
In high school, Joseph conducted research at the Heller Lab at Memorial Sloan Kettering Cancer Center. There, he contributed to projects focused on nanoparticle development and targeted drug delivery for breast cancer treatment, gaining hands-on experience in experimental design, cell monitoring, and literature review.

Joseph's early academic and research experiences continue to shape his commitment to using science and engineering as tools for innovation and social impact.

Eva Mescher was born in Newton, Massachusetts, in 2006. She graduated from Newton North High School in 2024. She is currently pursuing a B.S in Electrical Engineering at Northeastern University, Boston, MA, US.

In high school she focused on immersing herself in the study of engineering. She took many challenging engineering, math, and sciences classes. These classes inspired her to continue to grow and pursue engineering. She was also one of the leaders of the school's Programming club. She worked to lead activities and fun events for the club, improving her leadership skills. She furthered her learning by tutoring and helping other students in the study of math. During her first semester, she studied abroad in Thessaloniki, Greece, immersing herself in the city's culture. This experience allowed her to work and communicate with engineers from around the world, giving her a greater sense of global awareness.

Eva's academic background and passion for engineering have shaped who she is today.



Caroline DiMaio was born in Manhattan, New York, in 2006. She graduated from Oxbridge Academy of the Palm Beaches in 2024, where she developed a strong foundation in the sciences, particulary in biology. Her passion for biology led her to enroll in advanced science electives, and during high school, she had the unique opportunity to work as a research assistant for a small startup focused on prosthetic development- a connection made possible by one of her supportive science professors. This early exposure to real-world applications of science sparked her interest in the intersection of biology, technology, and design. Caroline is currently pursuing a B.S. in both Bioengineering and Mechanical engineering at Northeastern University. Her decision to enter the field of engineering was inspired by a desire to blend her creativity with her strong aptitude in math and science.

In her first semester of college, Caroline studied abroad in Rome, Italy, where she gained invaluable exposure to cultural and architectural diversity across Europe. This experience deepened her understanding of how engineering solutions must be tailored to fit different user needs – culturally, personally, and geographically – reinforcing her belief in user-centered design.

Caroline's passion for engineering continues to grow each day. With a multidisciplinary mindset, a global perspective, and a dedication to both creativity and innovation, she is eager to contribute meaningfully to the future of human-centered engineering.

APPENDICES:

APPENDIX A TEAM CONTRACT

<u>Team 1 Contract</u>

Contact Information:

Name	Joe Afflitto	Eva Mescher	Jonathan Chan	Caroline DiMaio
Email	jpafflitto@gmail.com	eva.mescher@gmail.com	jonathan.chan108@gmail.com	dimaiocaroline@gmail.com
Phone Number	929-375-7064	617-893-8555	732-586-1803	561-504-1831

<u>**Respect:**</u>
What is your definition of work lateness and policy for organized submission?
Work is considered late when a team member submits their assigned task past the agreed-upon deadline without a valid reason or notice. To avoid this, Team One will establish clear due dates and ensure all team members are aware of submission timelines. If a team member cannot complete their task on time, they must notify the team at least 24 hours before the deadline. This allows sufficient time for the team to readjust and redistribute tasks as needed.

What is your definition of meeting punctuality and procedure for a successful meeting?
For a successful meeting, all team members should arrive no later than five minutes after the scheduled start time, unless otherwise specified. Members are expected to come prepared with necessary materials and ready to actively participate. To stay focused, the team will follow an agenda shared at least 24 hours before the meeting, ensuring everyone has time to prepare. Meetings will conclude with a recap summarizing completed tasks, upcoming due dates, and next steps.

What will be the procedure if someone violates these expectations?
If a team member fails to meet expectations, the issue will be first addressed privately and respectfully by the team member who noticed it, providing constructive feedback. If the problem persists, it will be brought up during a team meeting, where the group can collaborate on solutions to support the individual. If the issue persists despite these efforts, the concern will be escalated to professor KSG or the TA for further guidance to ensure team goals and collaboration remain intact.

<u>**Commitment:**</u>
What hours do you expect people to be available to meet? Answer questions?
In-person meeting times will be previously established and upheld. It will be the individual's responsibility to ensure consistent attendance. If for whatever reason, a meeting can not occur the

individual must inform the group as soon as possible and potentially find a rescheduled date if necessary. Questions posed over text or email should expect a response within an hour, assuming it is of normal class hours. On weekends and late nights, response time will increase to multiple hours.

What will your expectations for quality be? / How will you measure this value?
The general expectation for work will be for each individual to put in the utmost effort and time into their portions of work, equalling the efforts and contributions of the fellow group members. This will largely be measured through group judgement and consensus, with grades and numerical results as further evidence of work discrepancy.

What will be the procedure if someone violates these policies?
Smaller, infrequent infractions will be forgiven so as to avoid major slowdown or conflict. If these offenses are repeated multiple times without proper reasoning, they will result in a group discussion designed to try to resolve the conflict and find a compromise. If the group can not come to an agreement or the agreement does not solve the issue, we will consult our mentor on the issue and consult them as mediators for the conflict.

<u>Transparency:</u>
How will your team make decisions?/ What will be the consensus?
To make decisions we will ensure that every team member has been given the opportunity to share their opinion. After everyone's ideas have been shared, we will all discuss and compare the pros and cons of each idea. To come to a consensus we don't have to use only one person's idea, we will try to incorporate many ideas and make compromises. If a consensus still cannot be reached we will each do more research to try and figure out the best course of action, and discuss further.

How will you ensure all information is shared and open to all?
We have created a shared google drive that all team members have access to. If we use other applications that are not compatible with google drive we will create another place where information can be shared like one drive. We will also communicate frequently about each team member's task so that everyone is in the loop on all the work that is being done. We also have a group chat with everyone so that we can quickly communicate if new information has not yet been shared.

What will be the procedure if someone feels excluded?
If someone feels excluded, they should mention it to their team members. If this person feels that just mentioning it is enough for others to change their behavior, then that is all that needs to be done. However, if they feel the group should have a discussion about it, it is important that all group members attend and listen to what they are saying. All information should be shared with

every group member, so if after the conversation occurs this person still feels excluded then they should bring it up with a TA or professor.

<u>Communication:</u>

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

To communicate efficiently, our primary form of communication will be over text messages and meetings. All team members have exchanged contacts to communicate when we're outside the classroom and not in person, which will help us get work done and support each other while working independently. In meetings, however, we will communicate our goals for the week to make sure everyone is on the same page for further communication.

How will you ensure everyone's voice is heard?

To ensure everyone's voice is heard, we will mutually agree to ask for everyone's opinion or stance on an issue that arises within the project. We will regularly ask each other to express feedback and suggestions from each member no matter how small the issue is and communicate it during meetings or even over text.

What will you do when there is a disagreement?

When disagreements arise, we will mutually agree to address them respectfully and constructively. First, we will allow each team member to present their perspective. Then, we will discuss potential solutions as a group, staying focused on the project's goals and criteria. If the disagreement cannot be resolved to no avail, we can consult with a professor or TA for more perspective guidance.

How will you periodically reflect on strengths and issues as a group? (provide a plan)

In order to address our strengths and issues, we will reserve a small portion of our meetings each week to express individual opinions on the progression of our project.

1. Strengths: Each team member will express aspects of the project that have been working well and how we can apply those successes to further project plans
2. Issues: Each team member will bring up potential concerns about their part and other sections of the project, announcing what has been slowing down the pace of work
3. Improvement: As a group, we will discuss potential solutions to help the workflow of specific parts of the project and designate more members to fill in.

<u>Justice:</u>

How will you define equitable contribution?

To ensure fairness, each team member will complete work that is comparable in weight, quality, and effort. While tasks may vary in type and complexity, every member is expected to contribute meaningfully to the project's overall progress. If a team member cannot complete their assigned work and communicates this to the team, they are expected to compensate by contributing additional support on the next assignment or assisting where needed. If any member feels overwhelmed, the team will adjust and redistribute tasks to maintain balance and productivity. Equitable contribution also includes active participation in discussions, consistent attendance, and being a dependable, engaged team member.

How will your group work to prevent conflict?
To prevent conflict, team members will address any concerns with the group as soon as possible to ensure a timely and collaborative response. This approach allows the team to work together on finding effective solutions and maintaining progress. If disagreements arise, they will be handled respectfully, with a focus on resolving the issue rather than placing blame. Team meetings will provide a supportive space for members to raise concerns, ensuring open communication and group problem-solving. To further avoid conflict, constructive feedback will be encouraged during meetings to reinforce a shared commitment to quality work and improvement.

What will be the procedure if someone stops contributing?
If a team member stops contributing, the issue will be addressed promptly and respectfully during the next team meeting. The team will offer support, including additional guidance, resources, or assistance to help the member re-engage with their responsibilities. If the team member continues to disengage despite the support provided, the concern may be escalated to Professor KSG or the TA to seek further guidance and ensure the project remains on track.

<u>Team Goals:</u>
Make a list of 4 or more goals as a team for improving your team skills

- Timely work schedule that consistently meets deadlines
- Quality communication that minimizes conflict and misunderstanding
- Producing high-quality work that meets the demands of the assignment and our own personal goals
- Receiving feedback from mentors and peers, and properly taking and using it as constructive criticism

Make a list of 2 or more goals for each individual (All need to answer)

- **Consistent Communication (Caroline)**
    - I am to be an active team member whether that be through sharing updates, asking questions or offering additional support to the group. I will be reliable in terms of quick response time, and actively participate in group meetings
- **High-quality work (Caroline)**
    - I will produce work that meets or exceeds the team's expectations and goals. I will do so by upholding proper time management skills, and asking for feedback to ensure quality work.

- **Communicating with an Engineer Mindset (Jonathan)**
    - I want to be able to communicate as an engineer in a semi-professional setting where I can learn how to convey my ideas clearly and concisely. This can be achieved by asking questions from mentors, giving feedback, and keeping track of promptly communicating project plans.
- **Documenting Research and Outcomes (Jonathan)**
    - I expect to produce quality work and research that I can continually document progress on. I hope to have a record of successes and positive outcomes from this project that I can present to future engineering opportunities.
- **Achieve Learning Goals and Gain Fundamental Engineering Skills (Joe)**
    - I hope to be able to grow and learn as a student and an engineer, being able to improve as a prospective engineer with the proper skills to move forward. I hope our group work excels in this aspect, being useful to learn how engineers may work in the professional world.
- **Build Communicating and Teamwork Skills (Joe)**
    - I hope to build my abilities to work with a new group of individuals and produce quality projects. I hope to grow in cooperating and brainstorming with others, and in doing so build valuable connections and friendships.
- **Strong collaboration and communication skills (Eva)**
    - My goal is to be able to work well with my teammates so that we can create a successful project. I will work on collaborating with my teammates and building off each other's ideas. Sometimes this means compromising or joining two ideas together.
- **Gaining a Complete Understanding of What I Learn (Eva)**
    - My goal is to gain an understanding of the engineering concepts we will learn, and how they are applied to the final project. Because this is a group project and we will each do separate parts of it while still working together, I want to make sure that I still understand how each part works even if I didn’t directly make it.

Team Roles:
Make a list of who will be the project manager for the four milestones
Milestone 1: Caroline
Milestone 2: Joe
Milestone 3: Eva
Milestone 4: Jonathan

Team Calendar:

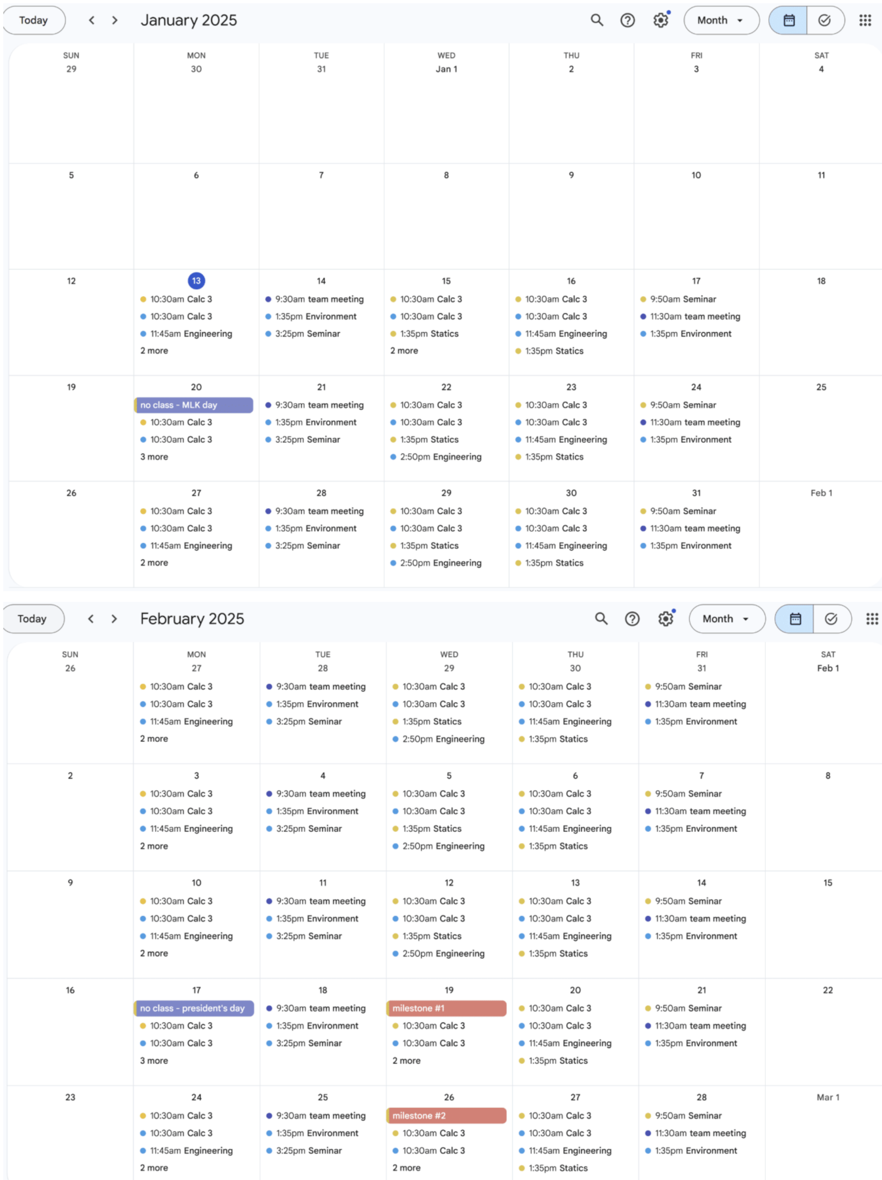
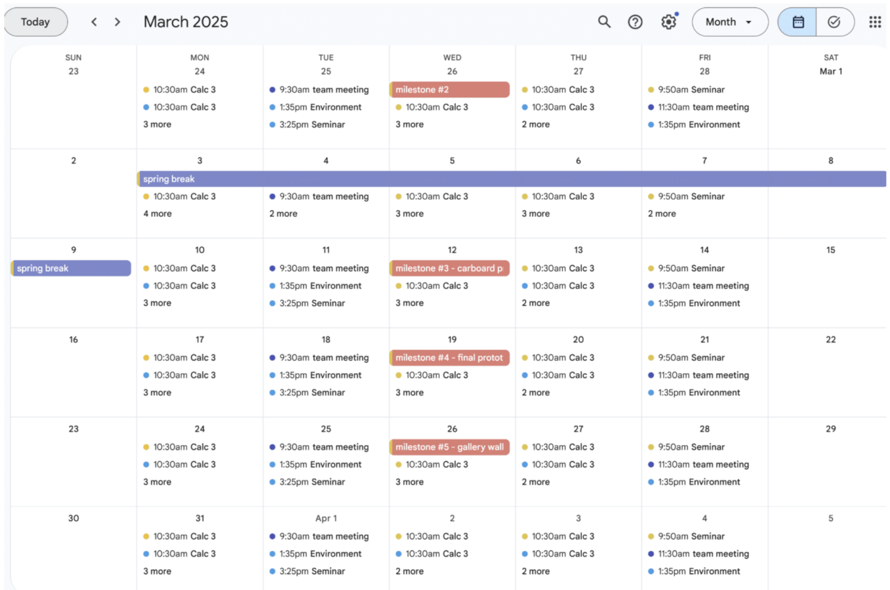
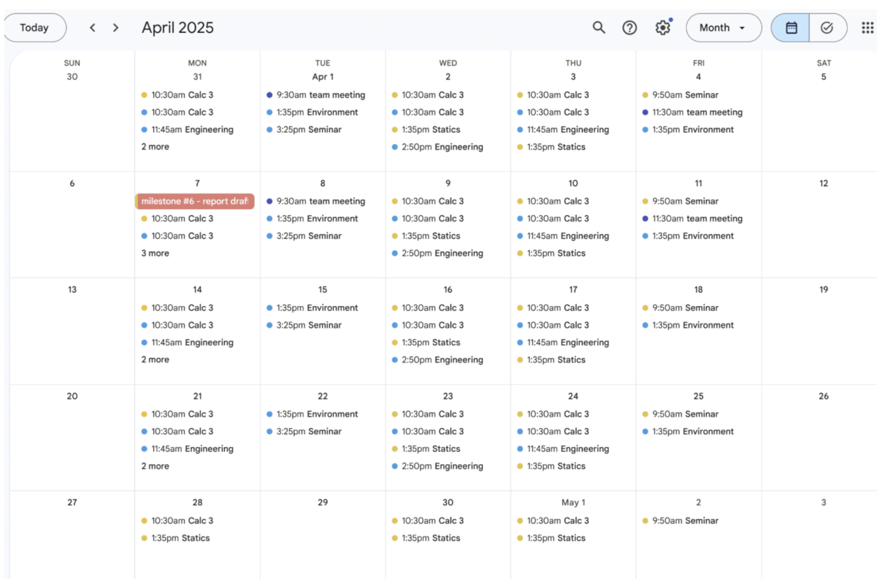


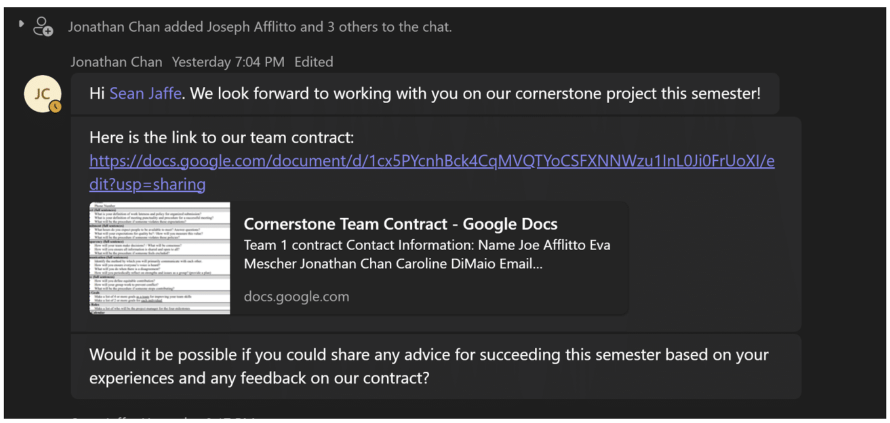
Fig. 4 - Team Calander

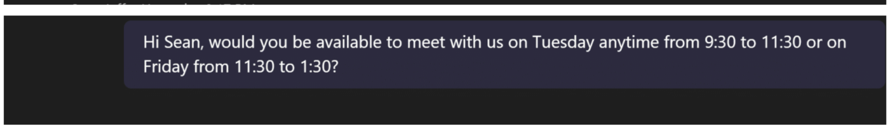

Today
March 2025
Month
SUN 23
MON 24
10:30am Calc 3
10:30am Calc 3
3 more
TUE 25
9:30am team meeting
1:35pm Environment
3:25pm Seminar
WED 26
milestone #2
10:30am Calc 3
3 more
THU 27
10:30am Calc 3
10:30am Calc 3
2 more
FRI 28
9:50am Seminar
11:30am team meeting
1:35pm Environment
SAT Mar 1
2
3
spring break
10:30am Calc 3
4 more
4
9:30am team meeting
2 more
5
10:30am Calc 3
3 more
6
10:30am Calc 3
3 more
7
9:50am Seminar
2 more
8
9
spring break
10
10:30am Calc 3
10:30am Calc 3
3 more
11
9:30am team meeting
1:35pm Environment
3:25pm Seminar
12
milestone #3 - carboard p
10:30am Calc 3
3 more
13
10:30am Calc 3
10:30am Calc 3
2 more
14
9:50am Seminar
11:30am team meeting
1:35pm Environment
15
16
17
10:30am Calc 3
10:30am Calc 3
3 more
18
9:30am team meeting
1:35pm Environment
3:25pm Seminar
19
milestone #4 - final protot
10:30am Calc 3
3 more
20
10:30am Calc 3
10:30am Calc 3
2 more
21
9:50am Seminar
11:30am team meeting
1:35pm Environment
22
23
24
10:30am Calc 3
10:30am Calc 3
3 more
25
9:30am team meeting
1:35pm Environment
3:25pm Seminar
26
milestone #5 - gallery wall
10:30am Calc 3
3 more
27
10:30am Calc 3
10:30am Calc 3
2 more
28
9:50am Seminar
11:30am team meeting
1:35pm Environment
29
30
31
10:30am Calc 3
10:30am Calc 3
3 more
Apr 1
9:30am team meeting
1:35pm Environment
3:25pm Seminar
2
10:30am Calc 3
10:30am Calc 3
2 more
3
10:30am Calc 3
10:30am Calc 3
2 more
4
9:50am Seminar
11:30am team meeting
1:35pm Environment
5


Today
April 2025
Month
SUN 30
MON 31
10:30am Calc 3
10:30am Calc 3
11:45am Engineering
2 more
TUE Apr 1
9:30am team meeting
1:35pm Environment
3:25pm Seminar
WED 2
10:30am Calc 3
10:30am Calc 3
1:35pm Statics
2:50pm Engineering
THU 3
10:30am Calc 3
10:30am Calc 3
11:45am Engineering
1:35pm Statics
FRI 4
9:50am Seminar
11:30am team meeting
1:35pm Environment
SAT 5
6
7
milestone #6 - report draf
10:30am Calc 3
10:30am Calc 3
3 more
8
9:30am team meeting
1:35pm Environment
3:25pm Seminar
9
10:30am Calc 3
10:30am Calc 3
1:35pm Statics
2:50pm Engineering
10
10:30am Calc 3
10:30am Calc 3
11:45am Engineering
1:35pm Statics
11
9:50am Seminar
11:30am team meeting
1:35pm Environment
12
13
14
10:30am Calc 3
10:30am Calc 3
11:45am Engineering
2 more
15
1:35pm Environment
3:25pm Seminar
16
10:30am Calc 3
10:30am Calc 3
1:35pm Statics
2:50pm Engineering
17
10:30am Calc 3
10:30am Calc 3
11:45am Engineering
1:35pm Statics
18
9:50am Seminar
1:35pm Environment
19
20
21
10:30am Calc 3
10:30am Calc 3
11:45am Engineering
2 more
22
1:35pm Environment
3:25pm Seminar
23
10:30am Calc 3
10:30am Calc 3
1:35pm Statics
2:50pm Engineering
24
10:30am Calc 3
10:30am Calc 3
11:45am Engineering
1:35pm Statics
25
9:50am Seminar
1:35pm Environment
26
27
28
10:30am Calc 3
1:35pm Statics
29
30
10:30am Calc 3
1:35pm Statics
May 1
10:30am Calc 3
1:35pm Statics
2
9:50am Seminar
3

Signatures:

Initial Contact with Mentor:





APPENDIX B EMPATHY MAP

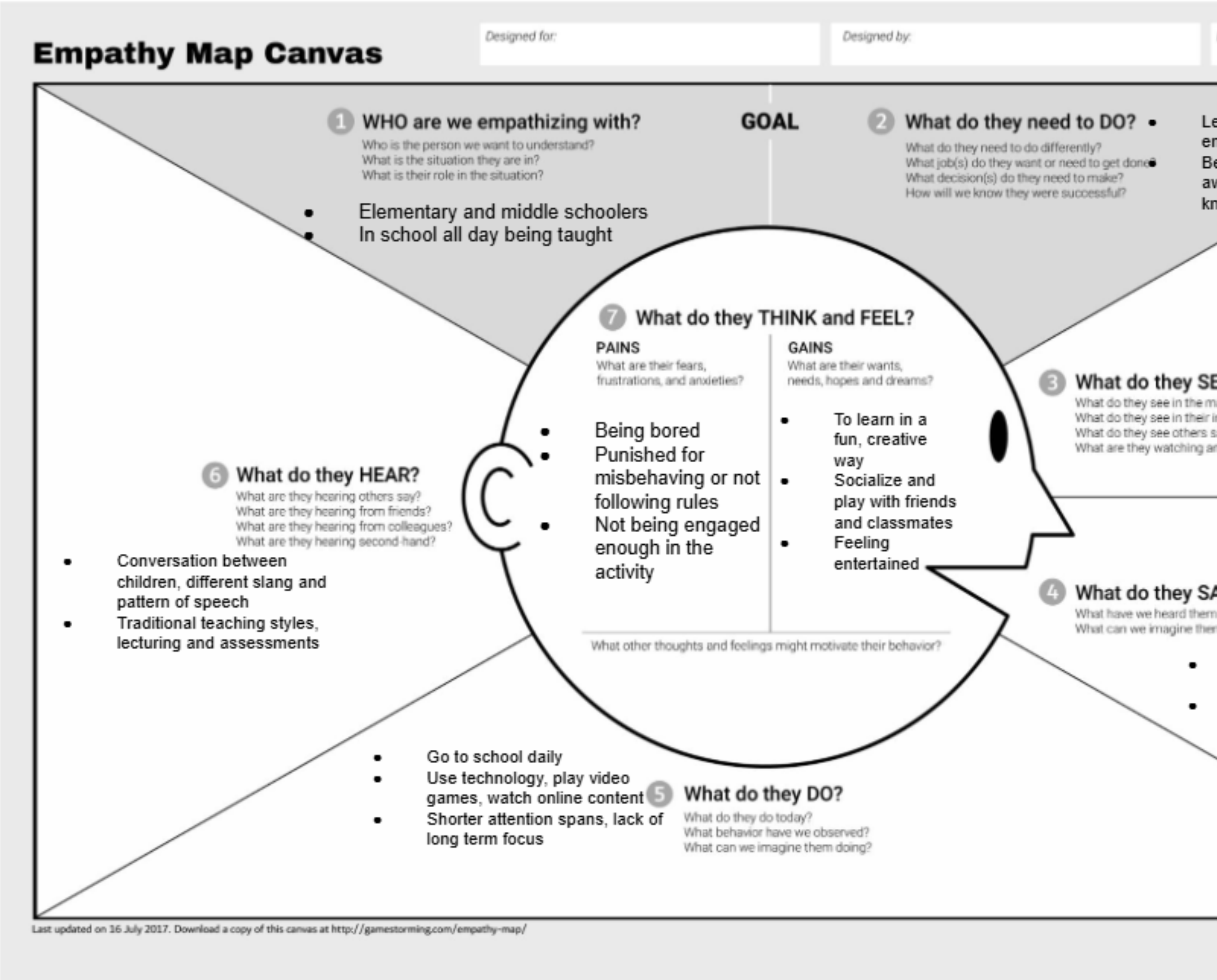


Fig. 4 – Empathy Map

APPENDIX C SOLUTION GENERATION

List of generated solution concepts

1 Carbon Capture

1.1 Start with familiar forms, trees, green spaces, planting

1.1.1 Photosynthesis, processes to remove CO_2 from these greens

1.1.2 Building blocks of tree, hands-on showing effects of levels on CO_2

1.2 Discuss more complex forms of capture

1.2.1 Interactive Chemical Reactions

- Collect CO_2 Molecules

1.2 Narrative Aspects

1.2.1 Polluted city (boston?), lacks proper carbon capture and sustainability techniques

1.2.2 Changes from users is reflected in visible environment

1.2.3 Combines ideas on tangible techniques (plants, trees) and advances to higher concepts of capture and reuse

1.2.4 Ties in water usage and relationship

1.2.5 Mini-game ->

- Collecting CO_2 molecules
- Building trees, use CO_2 molecules
- Take home element, result of collected CO_2
- CO_2 as a reward for lessons/games

2 Solid-state batteries

2.1 Building model/prototype of battery

2.1.1 If done right, light or machine powered and shown to students

2.2 Combine with solar?

2.2.1 Show how solar energy is collected, stored, and used

2.2.2 Previous idea, use the energy created/stored as power for visible stimuli (light, machine, etc)

2.3 Narrative Aspects

2.3.1 Collect power through the day, last through the night

2.3.2 Survival game aspects

2.3.3 Multiple nights, see difference in storage between battery types

- Longer lasting, easier to make, cost more with SS battery

2.3.4 Earn money from lessons

- Use for preparations in game

2.3.5 Excess money at the end of last night used for prizes?

3 Biogas

3.1 Process of collecting, converting, and using biogas

3.1.1 Collecting waste (cow farts, manure, crop scraps)

- Visual element when collected (air through tubes, water spray, etc?)

3.1.2 Physical pipes/process of conversion

- See changes occur as the users make changes in the game

3.2 Situational popups/challenges

3.2.1 Gain energy, store and use for later challenges

3.3 Narrative aspects

3.3.1 Animals in danger, need energy to move or protect them

3.3.2 Maintaining farm with energy production and waste reuse

1 Solar Grid

1.1 Power a city

1.1.1 Hospitals, schools, homes etc. each with their own productivity rates

1.1.2 Must decide where to send the solar energy

1.2 Weather spinner:

1.2.1 Sun is up and creates more energy

1.3 Events that require more energy (but have a bonus rate of productivity):

1.3.1 Battery malfunction

1.3.2 School Fair

1.3.3 Heatwave - more air conditioning

1.4 AI Bonus: Have AI support the energy production and distribution, boosting the energy you have in storage

1.5 Complete tasks to get more bonuses

1.5.1 Once you complete the tasks, you can finally save enough energy to produce a prize (ex. Keychain, etc.)

1) All Concept Sketches generated

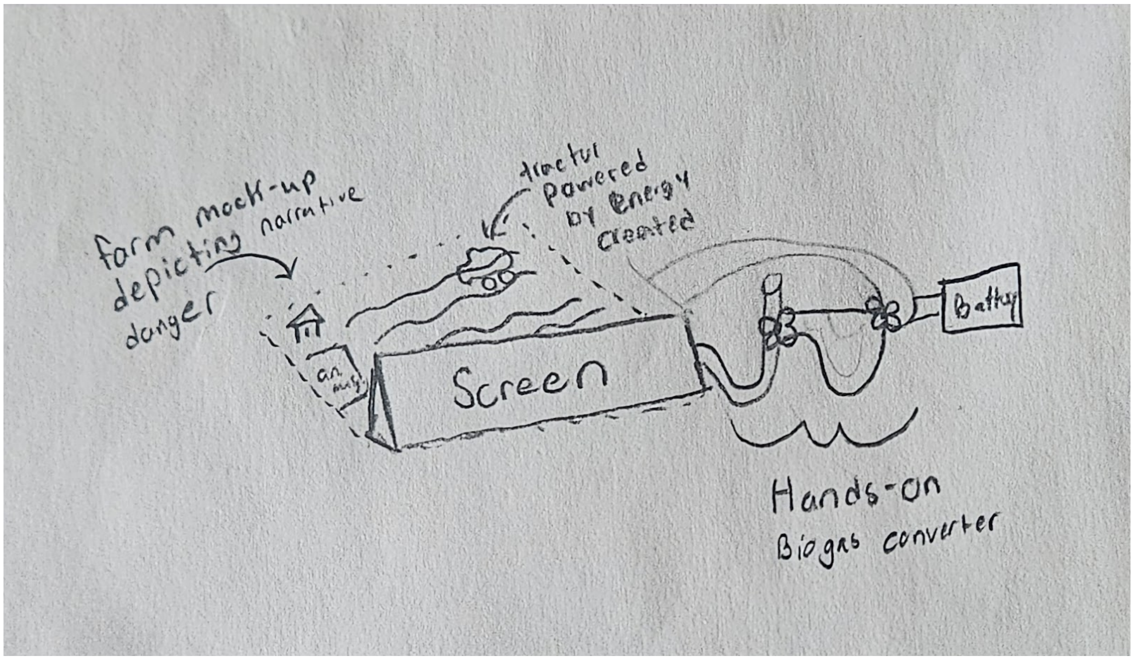

farm mock-up depicting narrative danger
powered by energy created
Screen
Battry
Hands-on
Biogas converter

Fig. 5 – Storyboarding Carbon Collection Sketch

Fig. 6 – Storyboarding Solar Grid Sketch

Fig. 7 - Storyboarding Battery Sketch

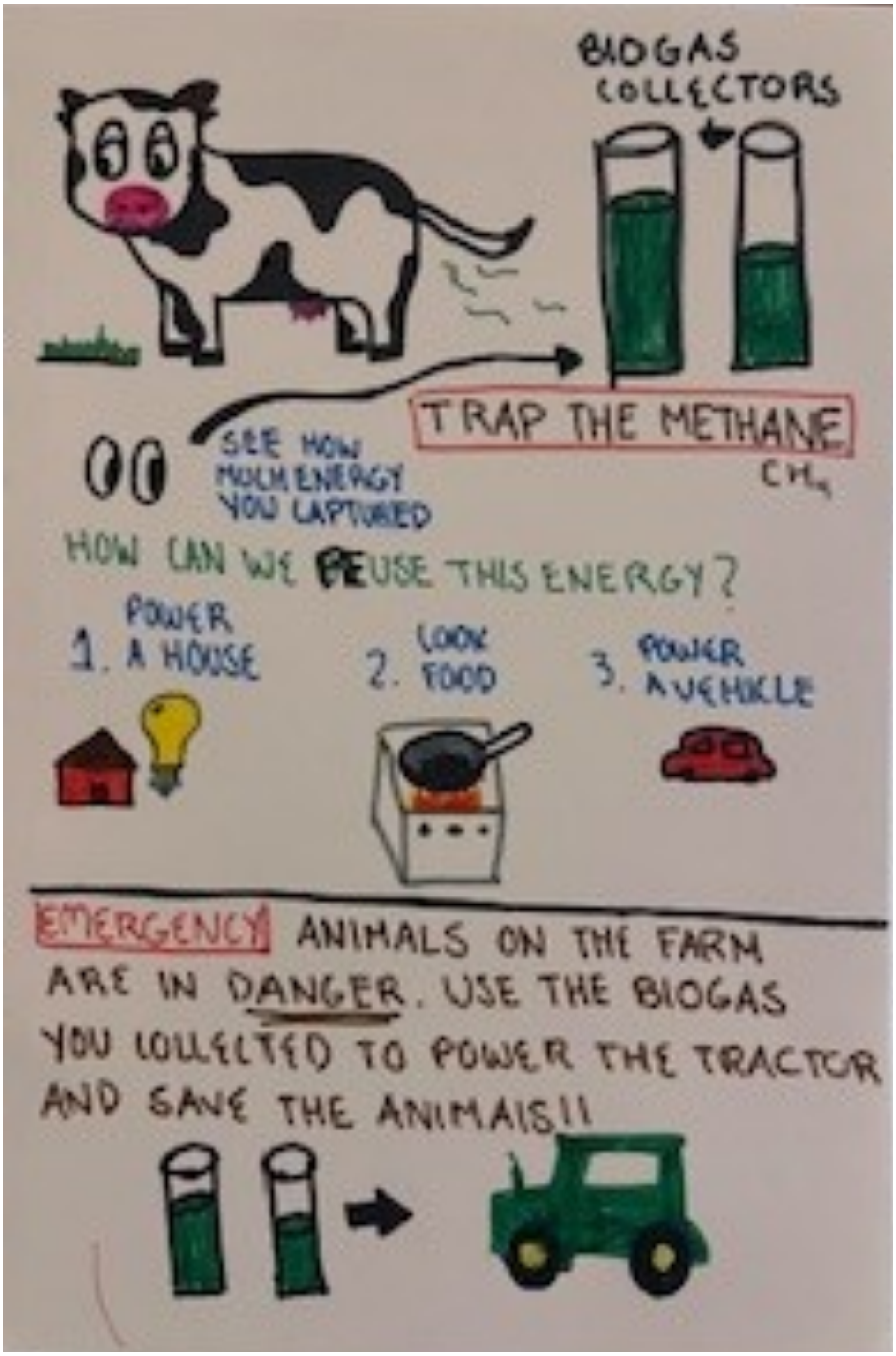


Fig. 8 - Storyboarding Biogas Sketch

APPENDIX D DECISION ANALYSIS

Musts		Biogas		Solar Grid		S-S Battery		Carbon Capture	
Safety		yes		yes		yes		yes	
Cost		yes		yes		yes		yes	
Wants	**Weight**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Interactive	9								
Gamify	2	8	16	6	12	9	18	7	14
Moving Parts	4	9	36	4	16	8	32	4	16
Hands on/physical components	3	8	24	6	18	8	24	9	27
Appeal	13								
Colorful	1	10	10	3	3	9	9	8	8
Inclusive	3	7	21	6	18	6	18	7	21
Relatability	4	4	16	8	32	7	28	8	32
Consistently Functional	2	8	16	8	16	6	12	7	14
Enaging and Fun	3	9	27	6	18	5	15	6	18
Educational	6								
Sustainability	3	9	27	7	21	10	30	7	21
Elementary Level Concepts	2	9	18	7	14	7	14	6	12
Market Articfacts (Take-Home E	1	7	7	7	7	5	5	5	5
Production	6								
Size Constraints	2	8	16	6	12	6	12	7	14
Independent Functioning	3	9	27	8	24	4	12	5	15
Feasibility	1	10	10	7	7	5	5	7	7
Total Scores:			**271**		**218**		**234**		**224**

Fig. 9 – K-T Decision Analysis

This K-T Decision Analysis evaluates four solutions—Biogas, Solar Grid, Solid-State Battery, and Carbon Capture—based on weighted criteria. All meet essential "Musts" like safety and cost, while "Wants" such as interactivity, appeal, and feasibility determine rankings. Biogas scores highest, followed by Solid-State Batteries, Carbon Capture, and Solar Grid, ensuring a data-driven selection.

APPENDIX E AUTOCAD/SOLIDWORKS DRAWINGS

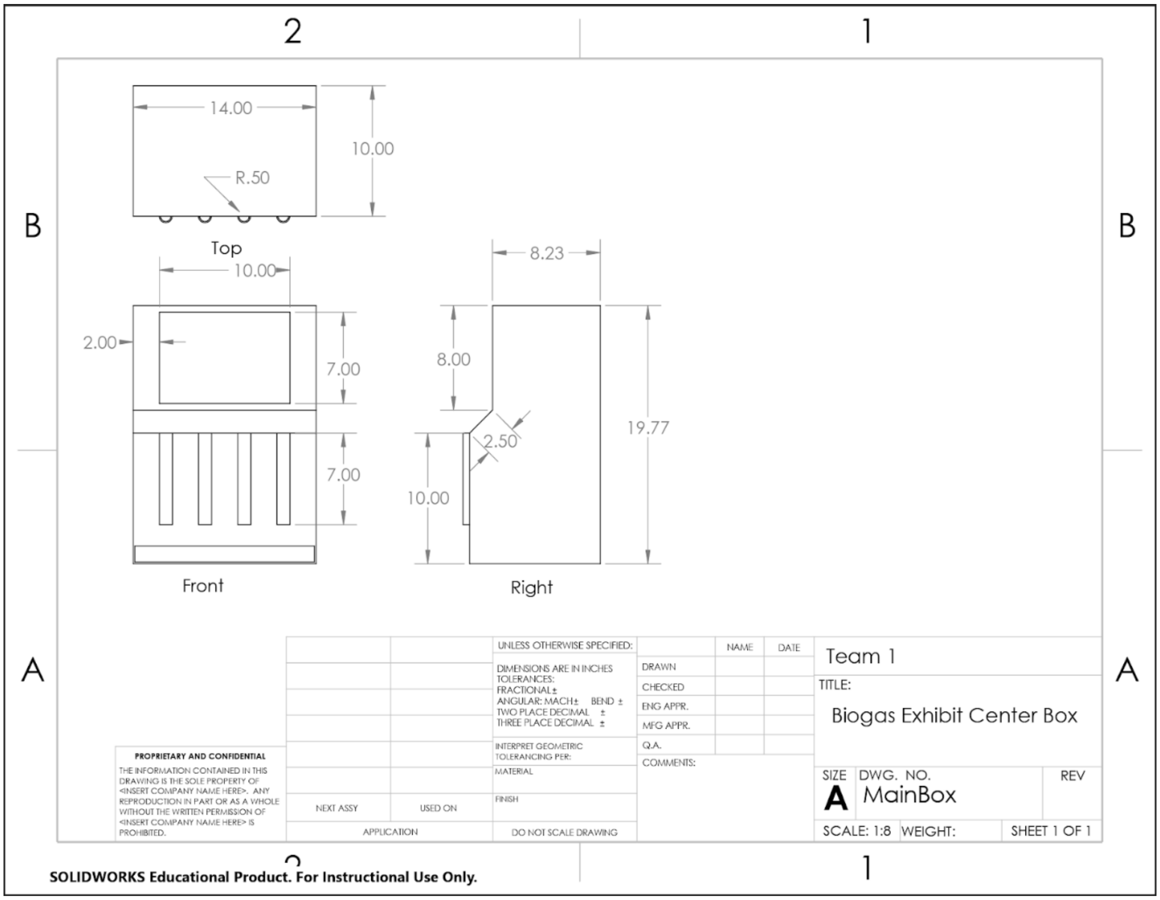


Fig. 10 - Center Box Drawing

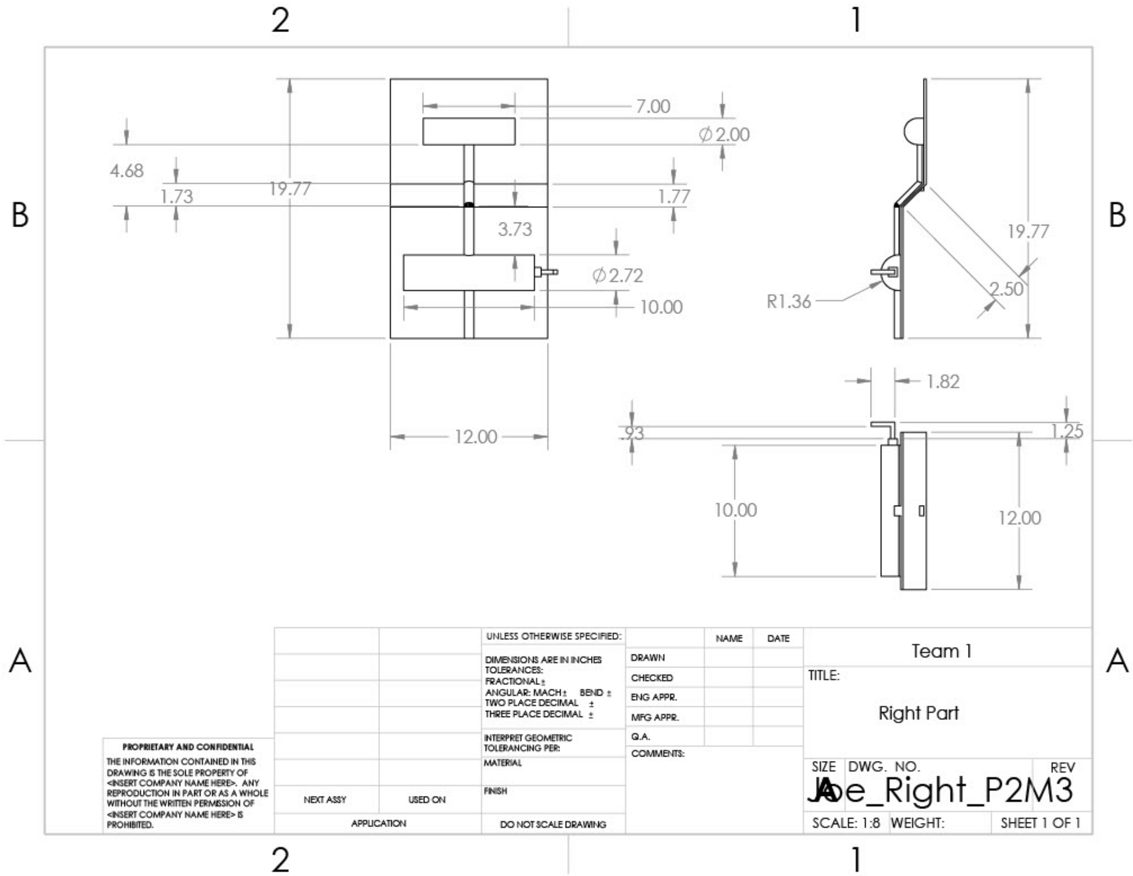


Fig. 11 - Right Panel Drawing

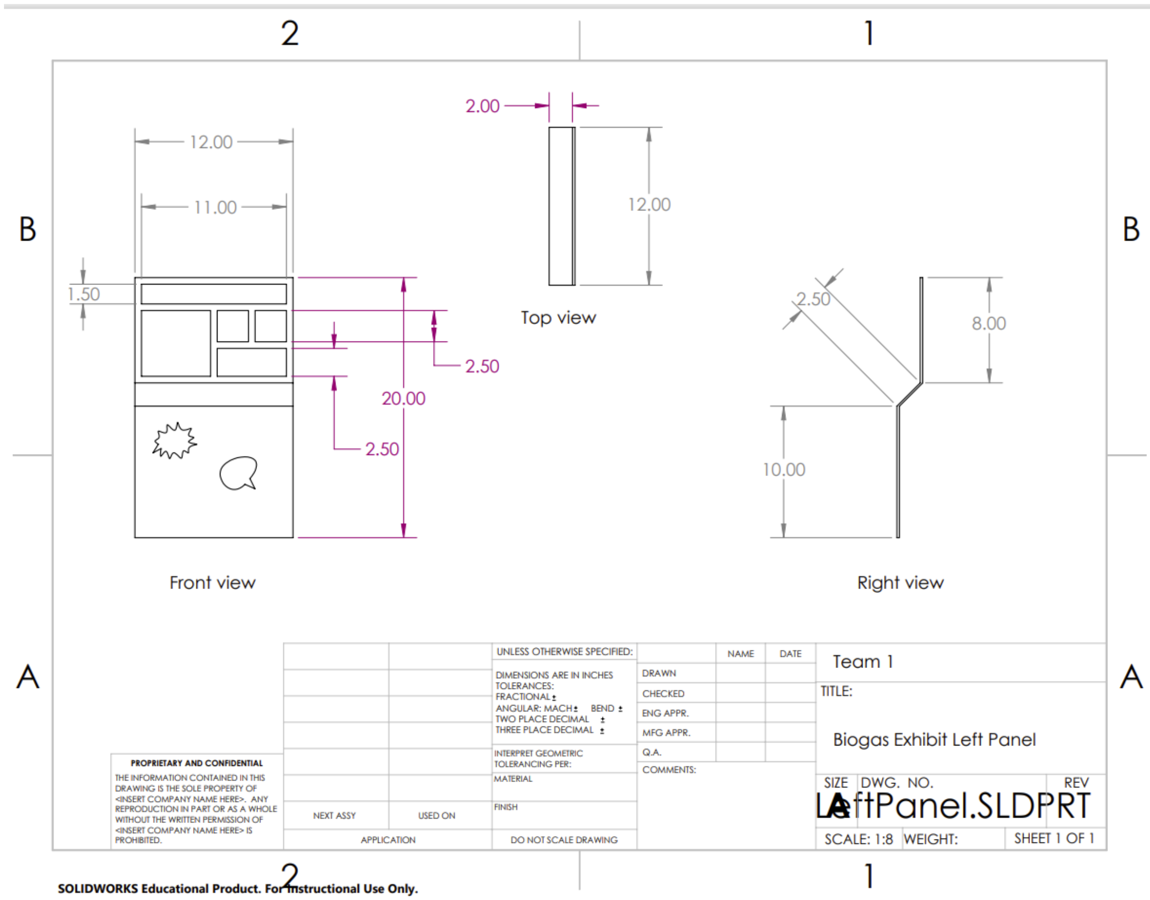


Fig. 12 - Left Panel Drawing

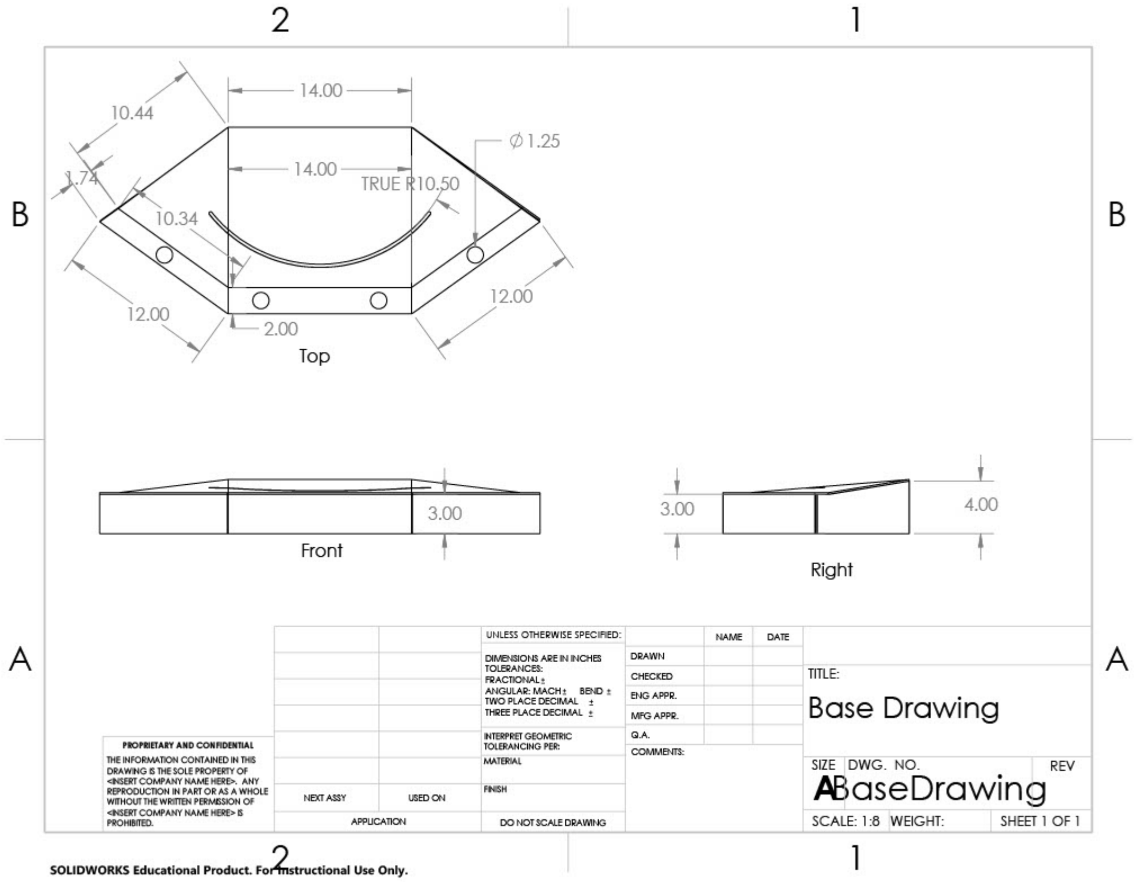


Fig. 13 - Base Drawing

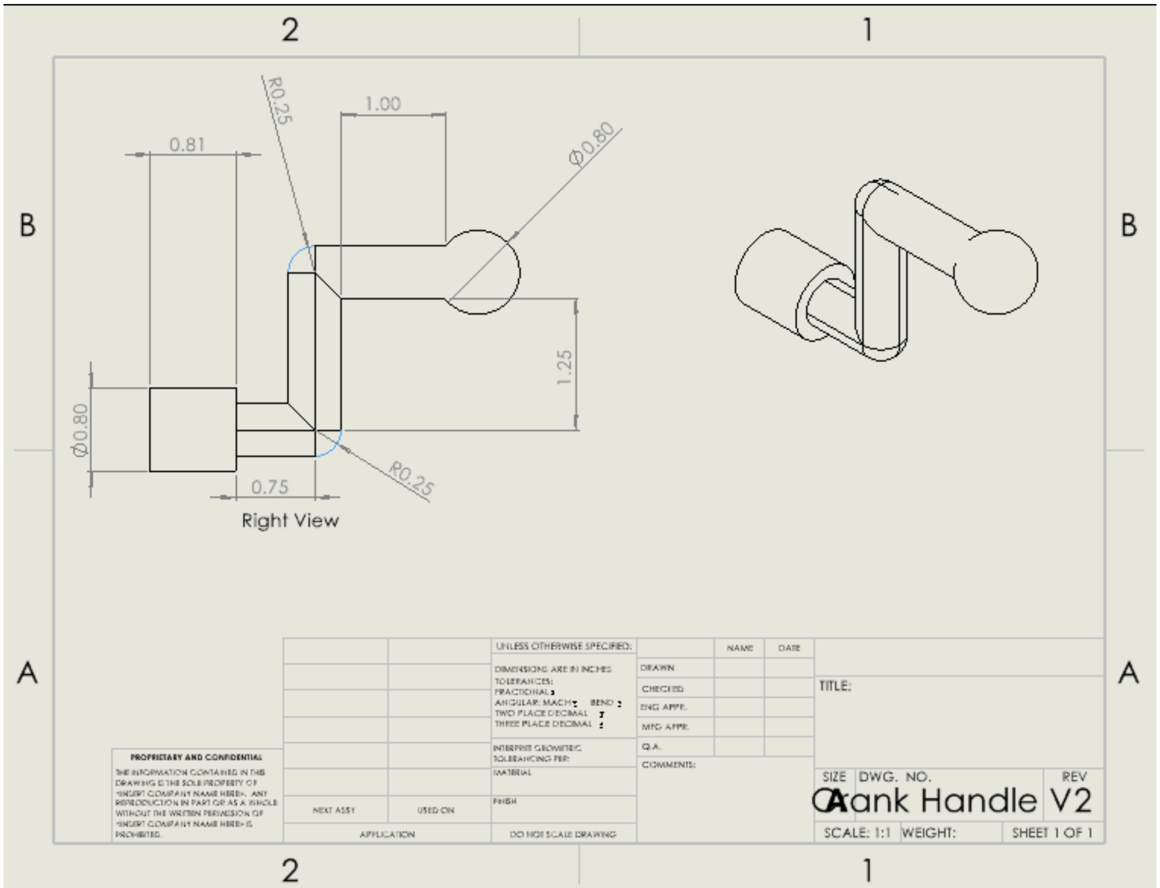


Fig. 14 – Crank Handle Drawing

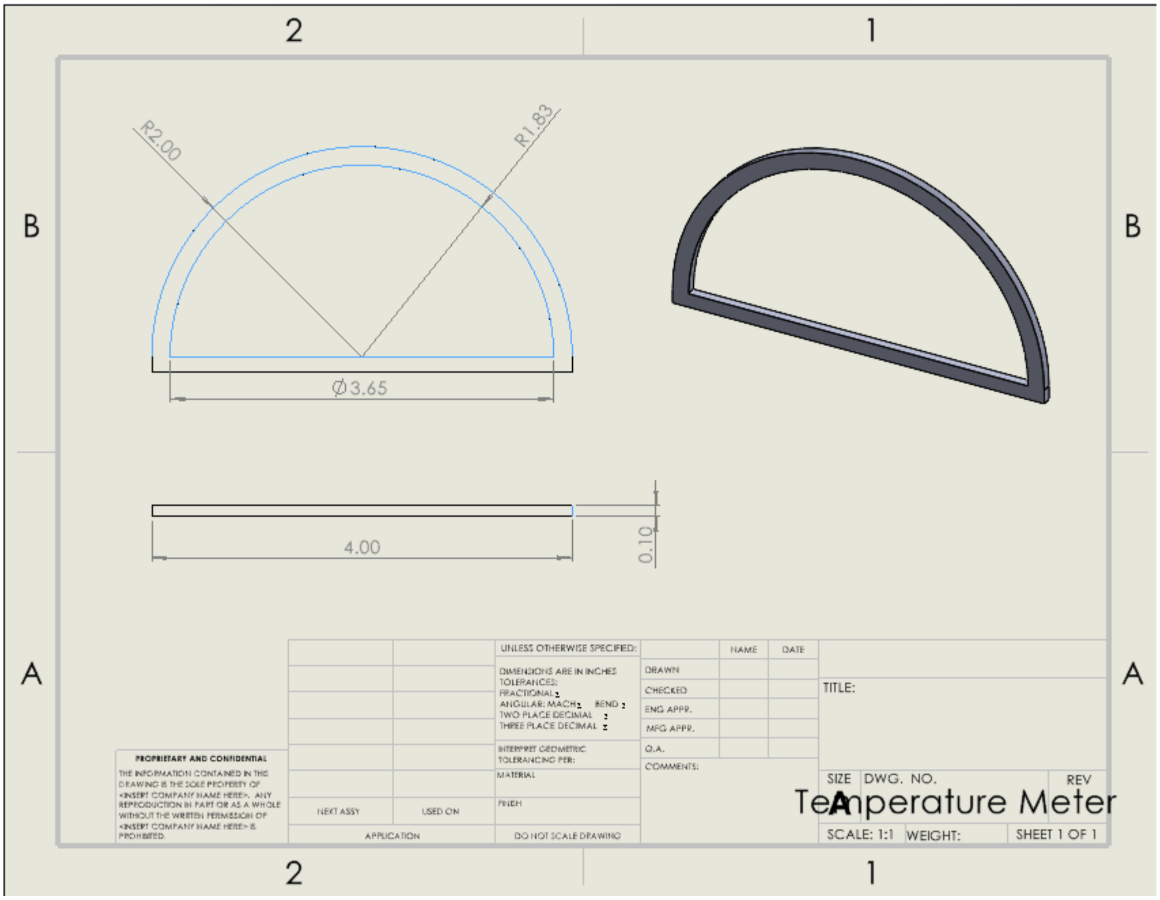


Fig. 15 – Temperature Meter Drawing

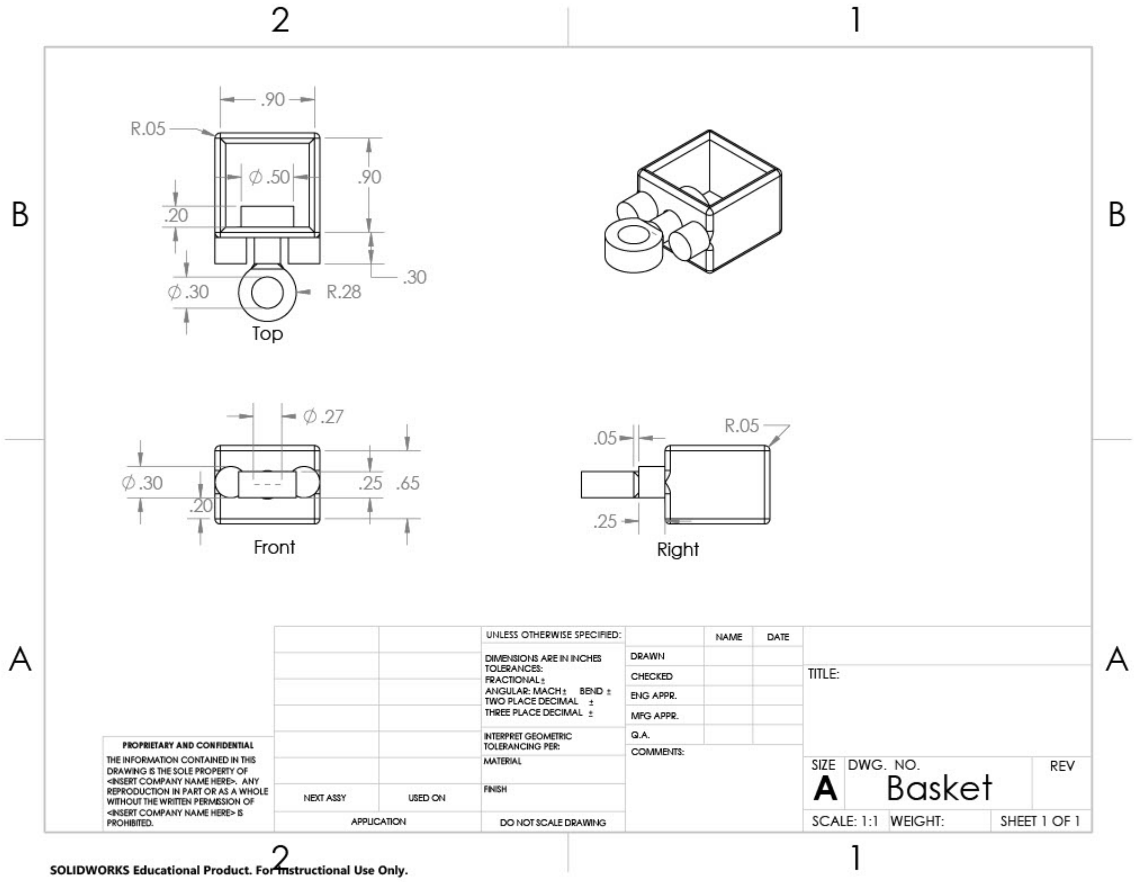


Fig. 16 – Basket Drawing

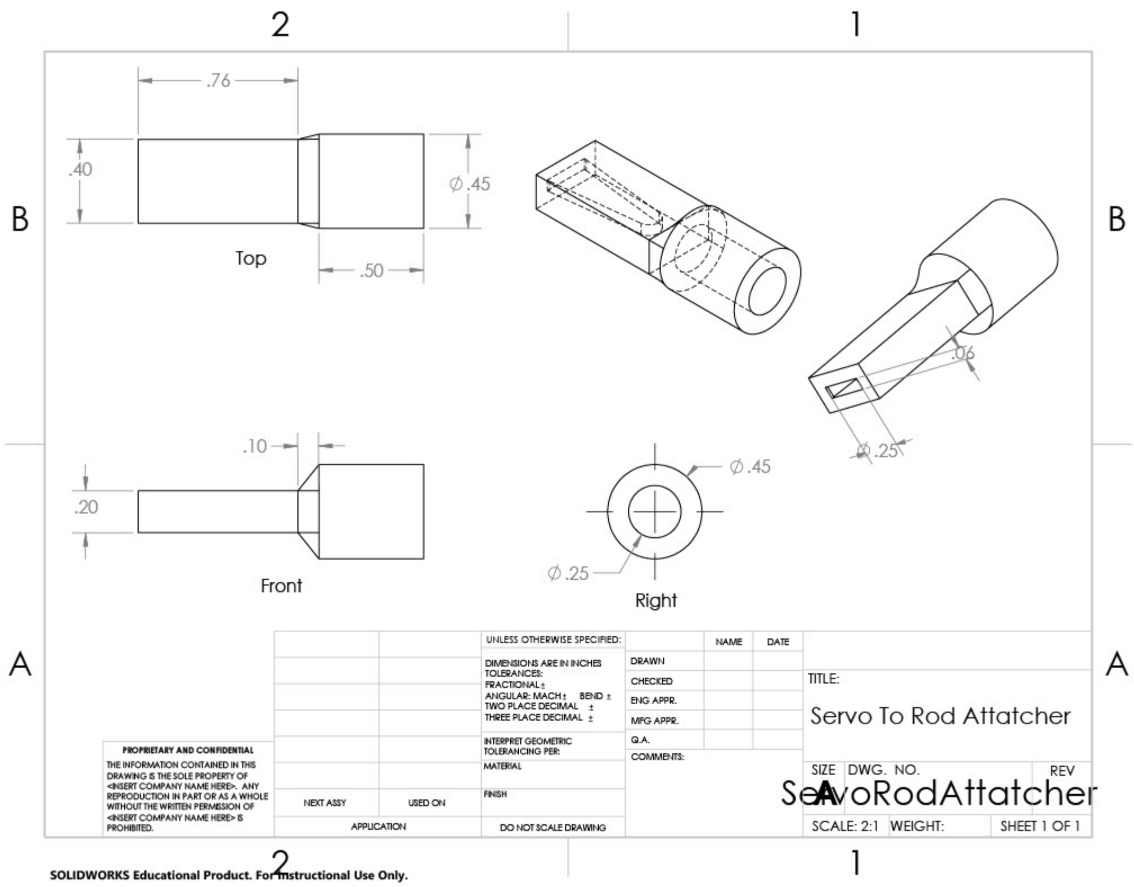


Fig. 17 – Servo Holder Drawing

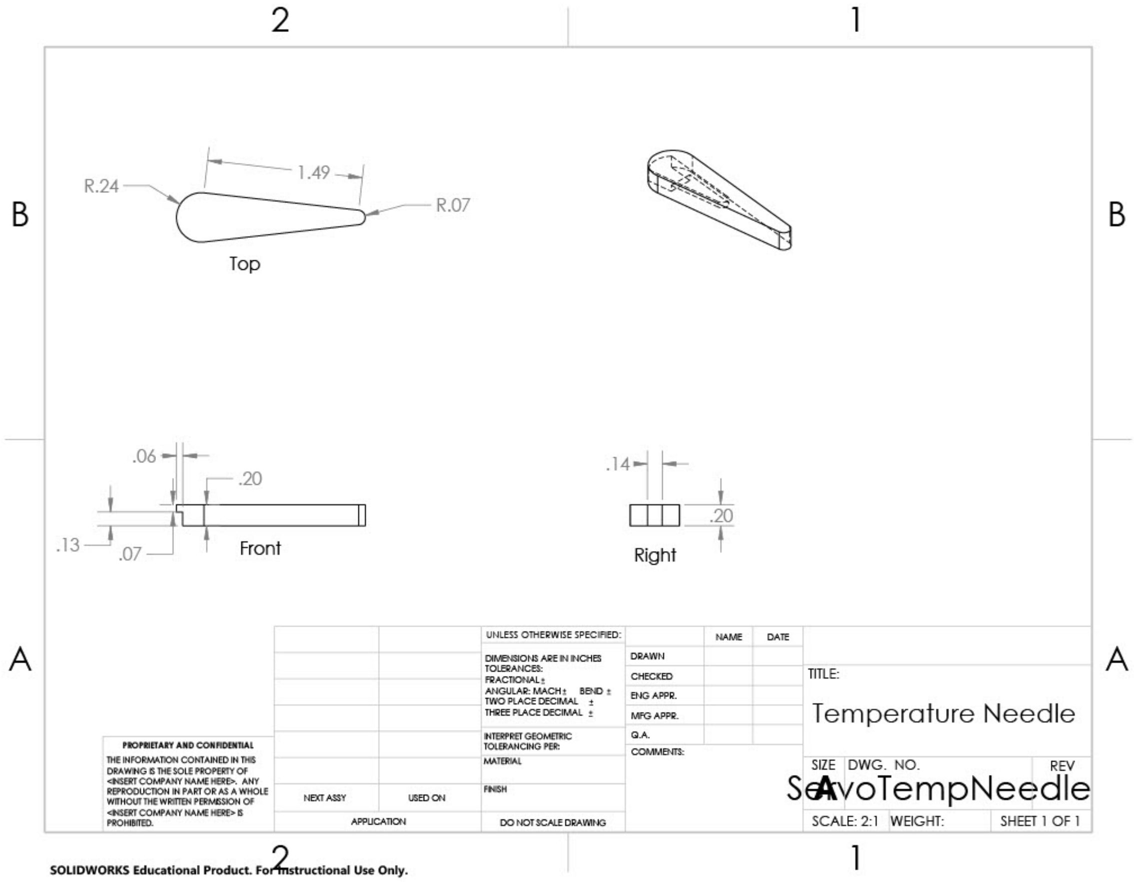


Fig. 18 - Temperature Needle Drawing

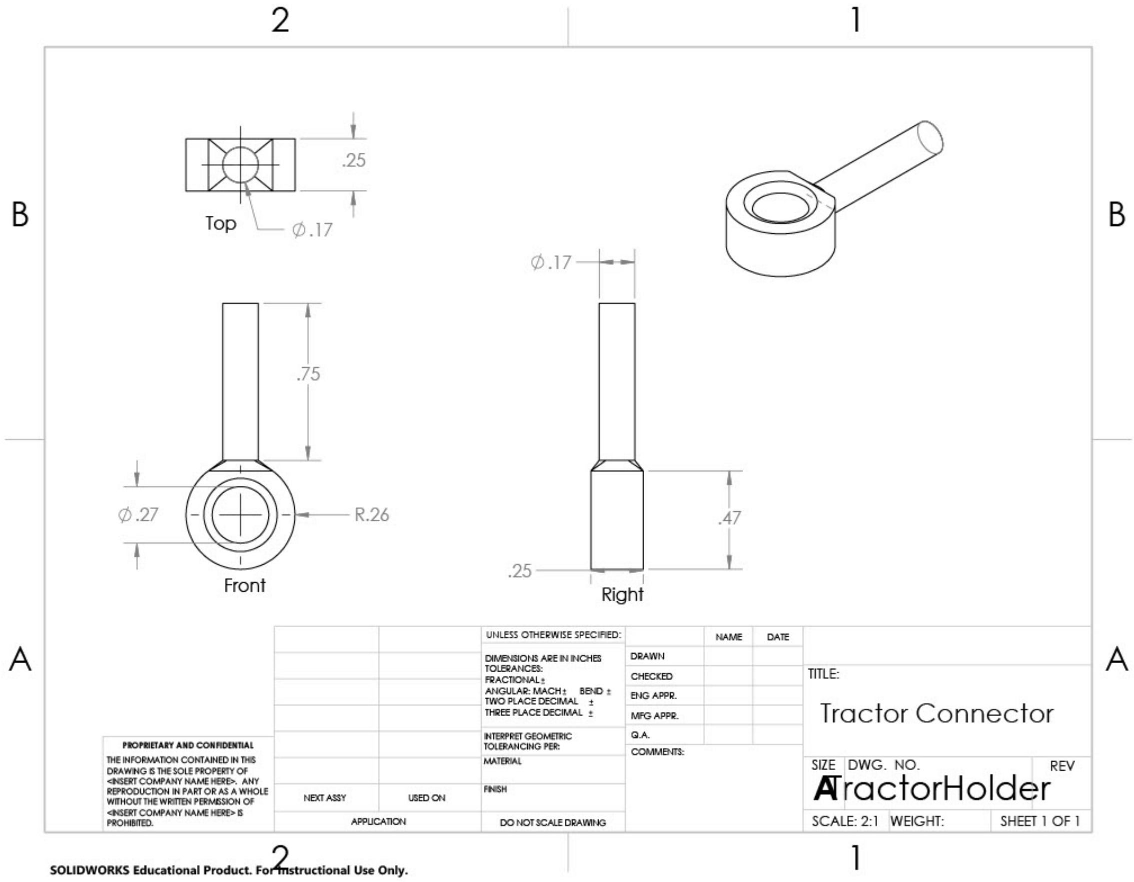


Fig. 19 - Tractor to Servo Connector Drawing

APPENDIX F PRODUCT TESTING RESULTS

Buckets Filled	Time to Fill Tank	Cranks Completed
2	54.60	588
1	161.03	5
1	57.67	563
3	54.68	581
3	55.60	609
3	42.53	569
1	57.06	643
2	55.80	552
3	56.72	511
3	51.68	526
3	43.59	599
2	46.66	594
4	57.40	668
4	58.50	0
3	44.15	534
5	46.65	576
4	38.82	564
3	55.38	686
4	46.83	533
3	56.48	500
4	57.58	623
2	52.90	602
2	62.89	643
3	57.36	584
2	65.19	619
4	53.86	587
3	52.15	591
5	56.55	440

KIDS

Buckets Filled	Time to Fill Tank	Cranks Completed
6	58.90	604
4	60.21	632
3	62.12	630
3	42.60	428
2	60.07	463
2	60.71	608
2	59.45	548
5	46.16	520
5	50.45	456
2	47.75	437
4	52.08	465
3	50.44	558
5	44.66	516
5	41.16	474
5	57.45	533
2	102.83	0
4	45.15	467
1	109.51	0

\

User Number	Feedback
1	Enjoyed the games, found the temperature game the most fun
2/3	Had a fun experience, enjoyed the crank aspect of the second game
4/5	Enjoyed the experience, found the second game the most fun
6/7	Found the exhibit fun, thought the chicken display/decorations were cute
8	Enjoyed, liked the aspect of saving the chickens with the power
9	Enjoyed overall, found the LED Waste game confusing at first but figured it out after a few mistakes
10	Found the games fun, liked how many games there were and how long they got to play on them

/ - indicate multiple users that interacted with exhibit together

APPENDIX G CODE USED IN PROJECT

Tractor Arduino Mock-Up Code:

```
#include <Servo.h>  // Include the Servo library

const int buttonPin = 10;  // Button pin
const int ledPin = 5;
Servo servo1;             // Create a servo object

const int minAngle = 0;   // Minimum angle
const int maxAngle = 180; // Maximum angle
int targetAngle = minAngle;  // Target position
int currentAngle = minAngle; // Servo's actual position
bool lastButtonState = HIGH; // Track previous button state

void setup() {
  pinMode(buttonPin, INPUT_PULLUP); // Use internal pull-up resistor
  pinMode(ledPin, OUTPUT);
  servo1.attach(11, 900, 2100); // Ensure servo range is valid
  servo1.write(currentAngle); // Set initial position
  Serial.begin(9600); // Start serial communication
}

void loop() {
  digitalWrite(ledPin, HIGH);
  bool buttonState = digitalRead(buttonPin); // Read button state

  // Detect button press (transition from HIGH to LOW)
  if (buttonState == LOW && lastButtonState == HIGH) {
    if (currentAngle == minAngle) {
      targetAngle = maxAngle; // Move to max angle
    } else if (currentAngle == maxAngle) {
      targetAngle = minAngle; // Move to min angle
    }
    Serial.print("Target angle set to: ");
    Serial.println(targetAngle);
    delay(300); // Small delay to prevent multiple triggers
  }

  lastButtonState = buttonState; // Store button state for next loop
```

```
  // Move the servo gradually
  if (currentAngle < targetAngle) {
    currentAngle++;
    servo1.write(currentAngle);
    delay(10); // Adjust delay for speed
  } else if (currentAngle > targetAngle) {
    currentAngle--;
    servo1.write(currentAngle);
    delay(10);
  }
}
```

Temperature Game Arduino Mock-Up Code:

```
#include <Servo.h>

// Function to run the game
void playGame(int buttonTemp, int CLK, int DT, int SW, int ledPin, int
servoPin) {
    // Game variables
    int temperature = 0;
    const int minTemp = 30;
    const int maxTemp = 50;
    const int crankGoal = 300;
    int crankCount = 0;
    bool gameRunning = false;
    bool gameOver = false;
    unsigned long tempInRangeStart = 0;
    bool tempHeld = false;

    // Rotary encoder variables
    int currentStateCLK;
    int lastStateCLK;

    // Servo setup
    Servo tempMeter;
    tempMeter.attach(servoPin);
```

```
    tempMeter.write(0); // Initialize servo to minimum position

    // Pin modes
    pinMode(ledPin, OUTPUT);
    pinMode(buttonTemp, INPUT_PULLUP);
    pinMode(CLK, INPUT);
    pinMode(DT, INPUT);
    pinMode(SW, INPUT_PULLUP);
    Serial.begin(9600);
    lastStateCLK = digitalRead(CLK);
    Serial.println("Press button to start the game!");

    // Start the game loop
    while (!gameOver) {
        digitalWrite(ledPin, HIGH);

        if (!gameRunning) {
            if (digitalRead(buttonTemp) == LOW) {
                Serial.println("Game started! Player 1: Press button to
heat up. Player 2: Crank to generate power!");
                temperature = 0;
                crankCount = 0;
                gameRunning = true;
                gameOver = false;
                tempInRangeStart = 0;
                tempHeld = false;
                tempMeter.write(0);
            }
            continue;
        }

        // Update Temperature
        static unsigned long lastTempUpdate = 0;
        if (digitalRead(buttonTemp) == LOW) {
            if (millis() - lastTempUpdate > 50) {
                temperature = min(temperature + 3, maxTemp + 10);
                Serial.println(temperature);
                lastTempUpdate = millis();
            }
        }

        if (millis() - lastTempUpdate >= 100) {
            temperature = max(temperature - max(3, temperature / 300), 0);
```

```
            Serial.println(temperature);
            lastTempUpdate = millis();
        }

        // Update Servo
        int servoAngle = map(temperature, 0, 70, 0, 180);
        tempMeter.write(servoAngle);

        // Update Crank Count
        currentStateCLK = digitalRead(CLK);
        if (currentStateCLK != lastStateCLK && currentStateCLK == 1) {
            if (digitalRead(DT) == currentStateCLK) {
                crankCount--;
            } else {
                crankCount++;
            }
            Serial.print("Crank Count: ");
            Serial.println(crankCount);
        }
        lastStateCLK = currentStateCLK;

        // Check Game Status
        if (crankCount >= crankGoal) {
            if (temperature >= minTemp && temperature <= maxTemp) {
                if (tempInRangeStart == 0) {
                    tempInRangeStart = millis();
                }
                if (millis() - tempInRangeStart >= 2000) {
                    gameRunning = false;
                    gameOver = true;
                    Serial.println("You won! The biogas system is
stable!");
                    Serial.println("Press reset to restart.");
                }
            } else {
                tempInRangeStart = 0;
            }
        }
    }
}
```

MATLAB Code


```
% repeats for multiple players
while true
    % sets up serial port communication
    lights = serialport("COM3", 9600);
    servo = serialport("COM4", 9600);
    flush(lights);
    flush(servo);
    configureTerminator(lights, "LF");
    configureTerminator(servo, "LF");

    % audio files
    [y, Fs] = audioread('collect.mp3');
    [y1, Fs1] = audioread('bad.mp3');
    [v1, F1] = audioread('vid1sound.mp3');
    [v2, F2] = audioread('vid2sound.mp3');
    [t, g] = audioread('completeTempGame.mp3');



    %%%%%%%%%%%%%%%%%%%%%%
    % Load the images
    bigImage = imread('big.jpg');
    startimage = imread("StartPhoto.png");
    tractorPic = imread("tractorPic.png");
    chickenCongrats = imread("chickenCongrats.png");

    images = {'apple.png', 'corn.png', 'banana.png', 'grass.png', 'poop.png', 'battery.↙
png', 'computer.png', 'trash.png', 'controller.png', 'plastic.png'};
    buckets = {"bucket0.png", "bucket1.png", "bucket2.png", "bucket3.png"};
    bucketcomplete = {"screen0.png", "screen1.png", "screen2.png", "screen3.png",↙
"screen4.png", "screen5.png", "screen6.png", "screen7.png", "screen8.png", "screen9.↙
png",};

    % load the videos
    vid1 = VideoReader('vid1.mp4');
    vid2 = VideoReader('vid2.mp4');
    tempAnimation = VideoReader('tempAnimation.mp4');

    % set up main figure
    screens = get(0, 'MonitorPositions');
    extendedMonitor = screens(2, :);
    figure(1);
    clf;
    set(gcf, 'Position', extendedMonitor, 'Name', "Biogas", 'Resize', 'off');

    % Set axes positions for each image
    yIcon = 0.1;
    % LED strip waste icon axis
    ax0 = axes(gcf, 'Position', [0, 0, 1, 1]);
    ax1 = axes(gcf, 'Position', [0.12, yIcon, 0.15, 0.25]);
    ax2 = axes(gcf, 'Position', [0.33, yIcon, 0.15, 0.25]);
```

```
ax3 = axes(gcf, 'Position', [0.56, yIcon, 0.15, 0.25]);
ax4 = axes(gcf, 'Position', [0.77, yIcon, 0.15, 0.25]);
% cloud axis
axc = axes(gcf, 'Position', [0.37, 0.30, 0.3, 0.4]);
% bucket axis
axb = axes(gcf, 'Position', [0.4, 0.35, 0.25, 0.35]);

% smaller progress collection axis
xs = 0.05;
ys = 0.8;
width = 0.1;
height = 0.15;
axi1 = axes(gcf, 'Position', [xs, ys, width, height]);
axi2 = axes(gcf, 'Position', [xs + 0.1, ys, width, height]);
axi3 = axes(gcf, 'Position', [xs + 0.2, ys, width, height]);
axi4 = axes(gcf, 'Position', [xs + 0.3, ys, width, height]);
axi5 = axes(gcf, 'Position', [xs + 0.4, ys, width, height]);
axi6 = axes(gcf, 'Position', [xs + 0.5, ys, width, height]);
axi7 = axes(gcf, 'Position', [xs + 0.6, ys, width, height]);
axi8 = axes(gcf, 'Position', [xs + 0.7, ys, width, height]);
axi9 = axes(gcf, 'Position', [xs + 0.8, ys, width, height]);

% array of smaller progress axis
axi = {axi1, axi2, axi3, axi4, axi5, axi6, axi7, axi8, axi9};
axfullnum = 1;

% turns off borders
axis(ax0, 'off');
axis(ax1, 'off');
axis(ax2, 'off');
axis(ax3, 'off');
axis(ax4, 'off');
axis(axb, 'off');
axis(axc, 'off');
axis(axi1, 'off');
axis(axi2, 'off');
axis(axi3, 'off');
axis(axi4, 'off');
axis(axi5, 'off');
axis(axi6, 'off');
axis(axi7, 'off');
axis(axi8, 'off');
axis(axi9, 'off');

axiss = [ax1,ax2,ax3,ax4];
figure(1);



% Parameters for the colorFall function
groupnum = 0;
```

```
oldgroup = -1;
start = [0, 20, 39, 58];
wdeg = [135, 111, 86, 60];
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
imshow(startimage, 'Parent', ax0);
flush(servo);

% tells arduino to start intro code
writeline(servo, "startintro");
while servo.NumBytesAvailable == 0 % wait for arduino to say button pressed
        pause(0.1);
end
readline(servo)
flush(servo);


%start video 1 and sound 1
sound(v1, F1);
figure(1);
speedFactor = 1.33;
frameDelay = 1 / (vid1.FrameRate * speedFactor);
while hasFrame(vid1)
    tic;
    frame = readFrame(vid1);
    imshow(frame, 'Parent', ax0);
    elapsed = toc;
    remainingTime = frameDelay - elapsed;
    if remainingTime > 0
        pause(remainingTime);
    end
end

cla(ax0);
imshow(bigImage, 'Parent', ax0);

% starts compost colection game
writeline(servo, "startservo");
fill = 0;
[img, ~, alpha] = imread("cloud.png");
monitor(img, alpha, axc);
[img, ~, alpha] = imread(buckets{fill + 1});
monitor(img, alpha, axb);

% user gets 25 types of waste
for i = 1:25
    flush(lights);
    flush(servo);
    writeline(servo, "startservo");
    % Ensure a different group number is selected
    % ensures waste falls from different strips each time
    while groupnum == oldgroup
```

```
            groupnum = randi([0, 3]);
        end
        oldgroup = groupnum;

        % randomizes type of waste (66% chance of good waste, 33% chance
        % for bad waste)
        rng('shuffle');
        gb = randi([0,2]);
        if gb < 2 % good
            rng('shuffle');
            numColor = randi([0, 4]);
        else % bad
            rng('shuffle');
            numColor = randi([5, 9]);
        end

        % uses monitor function to displaay waste icon onto correct axis
        [img, ~, alpha] = imread(images{numColor + 1});
        ax = axiss(groupnum + 1);
        monitor(img, alpha, ax);


        pause(0.5);
        % Send command to Arduino using serial (which color(waste type) and
        % which strip
        cmd = sprintf('colorFall %d %d\n', numColor, start(groupnum+1));
        write(lights, cmd, 'char');



        flush(lights);
        % waits for response from arduino to indicate when it is at the
        % bottom of the light strip
        while lights.NumBytesAvailable < 0
            pause(0.05);
        end
        readline(lights);
        flush(servo);
        pause(0.15);

        % reads the angle of the servo
        angle = readline(servo);
        angle = str2double(angle);

        % checks if angle is in correct range according to which strip fell
        % and if the waste is "good
        if angle > wdeg(groupnum + 1) - 10 && angle < wdeg(groupnum + 1) + 10 &&↙
numColor < 5
            sound(y, Fs); % Play good audio
            fprintf("collected: target: %d Angle: %d\n", wdeg(groupnum + 1), angle);
            cla(axb);
```

```
            fill = fill + 1;
            [img, ~, alpha] = imread(buckets{fill + 1});
            monitor(img, alpha, axb);

            % if bucket is filled add to tally at the top
            if fill == 3
                [img, ~, alpha] = imread("bucket3.png");
                monitor(img, alpha, axi{axfullnum});
                fill = 0;
                axfullnum = axfullnum + 1;
            end
        % if "bad" waste collected reset bucket state to empty
        elseif angle > wdeg(groupnum + 1) - 10 && angle < wdeg(groupnum + 1) + 10 &&↙
numColor > 4
            sound(y1, Fs1);
            fill = 0;
        end
        cla(ax);

        % if bucket state is empty display empty bucket
        if fill == 0
            cla(axb);
            [img, ~, alpha] = imread("bucket0.png");
            monitor(img, alpha, axb);
        end
        clc;
    end
    % tells arduino to stop basket servo coe
    writeline(servo, "end");
    % clears all axis
    cla(axb);
    cla(axc);
    cla(axi1);
    cla(axi2);
    cla(axi3);
    cla(axi4);
    cla(axi5);
    cla(axi6);
    cla(axi7);
    cla(axi8);
    cla(axi9);
    flush(lights);
    flush(servo);

    % shows completion screen based on number of buckets completed
    [img, ~, alpha] = imread(bucketcomplete{axfullnum});
    imshow(img, 'Parent', ax0);
    pause(5);
    cla(ax0);

    % second instructional video
```

```
sound(v2, F2);
figure(1);
speedFactor = 1.33;
frameDelay = 1 / (vid2.FrameRate * speedFactor);
while hasFrame(vid2)
    tic;
    frame = readFrame(vid2);
    imshow(frame, 'Parent', ax0);
    elapsed = toc;
    remainingTime = frameDelay - elapsed;
    if remainingTime > 0
        pause(remainingTime);
    end
end
cla(ax0);

%start crank game
writeline(lights, "startcrank");
while lights.NumBytesAvailable == 0 % wait for arduino to say game over
    pause(0.1);
end
oldCrank = 0;
tic;
while hasFrame(tempAnimation) && toc < 45
    frame = readFrame(tempAnimation);
    imshow(frame, 'Parent', ax0);
    % get angle and crank count from arduino
    line = readline(lights);
    data = str2double(strsplit(strtrim(line), ','));
    angle = data(1);
    crankCount = data(2);
    % pause animation if angle is not within correct range or if the
    % number of crank counts is stagnant
    while (crankCount <= oldCrank || angle < 60 || angle > 120) && toc < 45
        pause(0.03);
        line = readline(lights);  % Read a full line from Arduino
        data = str2double(strsplit(strtrim(line), ','));
        angle = data(1);
        crankCount = data(2);
        flush(lights);
    end
    flush(lights);
    oldCrank = crankCount;
    pause(1/(tempAnimation.FrameRate * 15));
end
writeline(lights, "stop");
sound(t, g);
pause(0.1);
flush(servo);
imshow(tractorPic, 'Parent', ax0);
```

```
    % start tractor game
    writeline(servo, "starttractor");

    while servo.NumBytesAvailable == 0 % wait for arduino to say game over
         pause(0.1);
    end

    imshow(chickenCongrats, 'Parent', ax0);
    pause(5);

    % write eval data to file
    fileID = fopen('Data.txt', 'a');
    fprintf(fileID, '%15d %20.2f %20d\n', axfullnum, toc, crankCount);
    fclose(fileID);

    cla(ax0);
    clear;
    clear;
end
```

MATLAB Monitor Function Code

4/22/25 2:03 AM C:\Users\evame\OneDrive - No...\monitor.m 1 of 1

```
function [] = monitor(img, alpha, axis)
figure(1);
% display image on specific axis
image('CData', flipud(img), 'AlphaData', flipud(alpha), 'Parent', axis);
```

Arduino Board #1 Code

```
#include <Adafruit_NeoPixel.h>
#define LED_PIN     6
#define LED_COUNT  100
#define BRIGHTNESS 50 // Set BRIGHTNESS to about 1/5 (max = 255)


// Declare our NeoPixel strip object:
Adafruit_NeoPixel strip(LED_COUNT, LED_PIN, NEO_GRBW + NEO_KHZ800);
// Argument 1 = Number of pixels in NeoPixel strip
// Argument 2 = Arduino pin number (most are valid)
// Argument 3 = Pixel type flags, add together as needed:
//   NEO_KHZ800  800 KHz bitstream (most NeoPixel products w/WS2812 LEDs)
//   NEO_KHZ400  400 KHz (classic 'v1' (not v2) FLORA pixels, WS2811
drivers)
//   NEO_GRB     Pixels are wired for GRB bitstream (most NeoPixel
products)
//   NEO_RGB     Pixels are wired for RGB bitstream (v1 FLORA pixels, not
v2)
//   NEO_RGBW    Pixels are wired for RGBW bitstream (NeoPixel RGBW
products)

// good
uint32_t red = strip.Color(255,   0,   0); //apple
uint32_t orange = strip.Color(255,165,0); // corn
uint32_t yellow = strip.Color(255, 180, 0); // banana
uint32_t green = strip.Color(0,   255,   0); // grass
uint32_t brown = strip.Color(255, 45, 0); // poop

// bad
uint32_t blue = strip.Color(0,   0,   255); // battery
uint32_t purple = strip.Color(179,25,255); // computer
uint32_t gray = strip.Color(140, 140, 140); // trash
uint32_t dgray = strip.Color(64,69,71); // game controller
uint32_t white = strip.Color(0,   0, 0, 255); // plastic

uint32_t off = strip.Color(0, 0, 0, 0);


int length = 16;
int wait = 100;
```

```
uint32_t color[] = {red, orange, yellow, green, brown, blue, purple, gray,
dgray, white};
///////////////////////////////////////////////////////////////////////////
////////////////
// CRANK GAME
#include <Servo.h>

// Pin definitions
const int buttonTemp = 10; // Player 1 button to increase temperature
#define CLK 2  // Player 2 rotary encoder clock pin
#define DT 3   // Player 2 rotary encoder data pin
#define SW 4   // Player 2 rotary encoder switch pin
const int led4 = 9;

// Game variables
int temperature = 0; // Initial temperature
const int minTemp = 30;  // Minimum target temperature
const int maxTemp = 50;  // Maximum target temperature
const int crankGoal = 300; // Number of cranks needed
int crankCount = 0;
bool gameRunning = false;
bool gameOver = false;
unsigned long tempInRangeStart = 0;
bool tempHeld = false;

// Rotary encoder variables
int currentStateCLK;
int lastStateCLK;

// Servo for temperature meter
Servo tempMeter;
const int servoPin = 11;
const int minAngle = 0;
const int maxAngle = 180;
int angle = 0;
int stepSize =3;

///////////////////////////////////////////////////////////////////////////
////////////////

void setup() {
  strip.begin();
  strip.show();
```

```
  strip.setBrightness(BRIGHTNESS);
  Serial.begin(9600);

  // initializing pin mode types
  pinMode(led4, OUTPUT);
  pinMode(buttonTemp, INPUT_PULLUP);
  pinMode(CLK, INPUT);
  pinMode(DT, INPUT);
  pinMode(SW, INPUT_PULLUP);

  lastStateCLK = digitalRead(CLK);
  Serial.println("Press button to start the game!");

  // Attach servo
  tempMeter.attach(servoPin);
  tempMeter.write(180);
}

void loop() {
  // if something in serial port
  if (Serial.available()) {
    String command = Serial.readStringUntil('\n'); // Read command
    // for composest collection game
    if (command.startsWith("colorFall")) {
      int firstSpace = command.indexOf(' ');
      int secondSpace = command.indexOf(' ', firstSpace + 1);
      int thirdSpace = command.indexOf(' ', secondSpace + 1);

      // gets values for colar fall function
      int colorNum = command.substring(firstSpace + 1,
secondSpace).toInt();
      int startPos = command.substring(secondSpace + 1,
thirdSpace).toInt();
      uint32_t colorVal = color[colorNum];

      // calls color fall funcion
      colorFall(colorVal, startPos);
    }

    // for temperature game
    if (command == "startcrank"){
      // turn on red temp button LED
      digitalWrite(led4, HIGH);
```

```
      while (true)
      {
        if (digitalRead(buttonTemp) == LOW) // Right button pressed
        {
          // move if button pressed to the right
          angle -= stepSize;
          angle = constrain(angle, minAngle, maxAngle);
          //Serial.println(angle);
          tempMeter.write(angle);
          delay(20);
        }
        else { // otherwise decrease the angle
          angle += stepSize;
          angle = constrain(angle, minAngle, maxAngle);
          tempMeter.write(angle);
          delay(20);
        }
        // add to crank count
        if (digitalRead(CLK) == HIGH && lastStateCLK == LOW) {
          crankCount++;  // Always increment
        }
        lastStateCLK = digitalRead(CLK);
        // print angle and crank count to MATLAB
        Serial.print(angle);
        Serial.print(", ");
        Serial.println(crankCount);
        // if told to stop from MATLAB turn off button LED and break the
loop
        if (Serial.available() && Serial.readStringUntil('\n') == "stop")
        {
          digitalWrite(led4, LOW);
          break;
        }
      }
    }



  }

}

void colorFall(uint32_t color, int start)
```

```
{
  // repeats length of the LED strip times
  for (int i = 0; i < length; i++)
  {
    // turn on next LED
    strip.setPixelColor(start + i, color);
    // turn off the LED 3 behind
    strip.setPixelColor(start + i - 3, off);
    strip.show();

    if (i > length - 2) // last three
    {
      // tell matlab at the end of the strip
      Serial.println("end");
    }
    delay(wait);
  }
  strip.clear();
}



void updateCrankCount() {
    currentStateCLK = digitalRead(CLK);
    // changing crank count
    if (currentStateCLK != lastStateCLK && currentStateCLK == 1) {
        if (digitalRead(DT) == currentStateCLK) { // Swapped the condition
            crankCount--;
        } else {
            crankCount++;
        }
    }
    lastStateCLK = currentStateCLK;
}
```

Arduino Board #2 Code

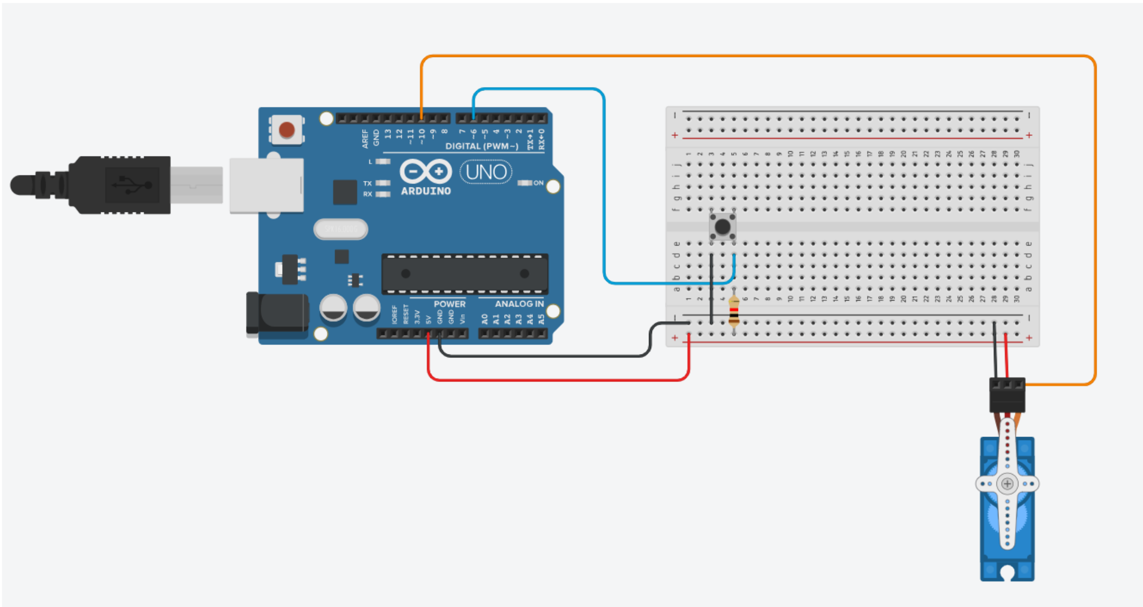
```
#include <Servo.h>  // Include the Servo library

const int button1 = 8;
const int buttonL = 3;  // Button to decrease angle
const int buttonR = 4;  // Button to increase angle

int LED1 = 5;
int LEDL = 7;
int LEDR = 6;

// create servo object
Servo servo1;
Servo servo2;

int angle = 90;         // Start at a neutral position (90 degrees)
const int minS = 55;
const int maxS = 145;
const int stepSize = 3; // Angle increment/decrement step
const int waitTime = 20;
const int tmax = 150;
const int tmin = 40;
int angleT = tmax;
int tdelay = 100;

void setup() {
  Serial.begin(9600);
  // initialize pinmodes
  pinMode(button1, INPUT_PULLUP);
  pinMode(buttonL, INPUT_PULLUP);
  pinMode(buttonR, INPUT_PULLUP);
  pinMode(LEDR, OUTPUT);
  pinMode(LEDL, OUTPUT);
  pinMode(LED1, OUTPUT);
  // bucket servo
  servo1.attach(9); // Attach servo to pin 9
  servo1.write(angle); // start at 90 deg
  servo2.attach(11);
  // tractor servo
  servo2.write(tmax); // start at tmax
}
```

```
void loop() {
  // if info from matlab
  if (Serial.available())
  {
    String command = Serial.readStringUntil('\n');  // Read command from
MATLAB
    command.trim();  // Remove any extra spaces or newlines
    // very beginning
    if (command == "startintro")
    {
      while (digitalRead(buttonR) == HIGH) // waiting for button press
      {
        digitalWrite(LEDL, HIGH);
        delay(30);
      }
      Serial.println("readytostart");
      digitalWrite(LEDL, LOW);
    }

    // BUCKET SERVO
    while(command == "startservo")
    {
      // trun on middle LED's
      digitalWrite(LEDL, HIGH);
      digitalWrite(LEDR, HIGH);
      Serial.println(angle); // communicate angle to MATLAB
      delay(10);
      if (digitalRead(buttonR) == LOW) // Right button pressed
      {
        // increase servo angle
        angle += stepSize;
        angle = constrain(angle, minS, maxS);
        servo1.write(angle);
        delay(waitTime);
      }
      if (digitalRead(buttonL) == LOW) // Left button pressed
      {
        // decrease servo angle
        angle -= stepSize;
        angle = constrain(angle, minS, maxS);
        servo1.write(angle);
        delay(waitTime);
      }
```

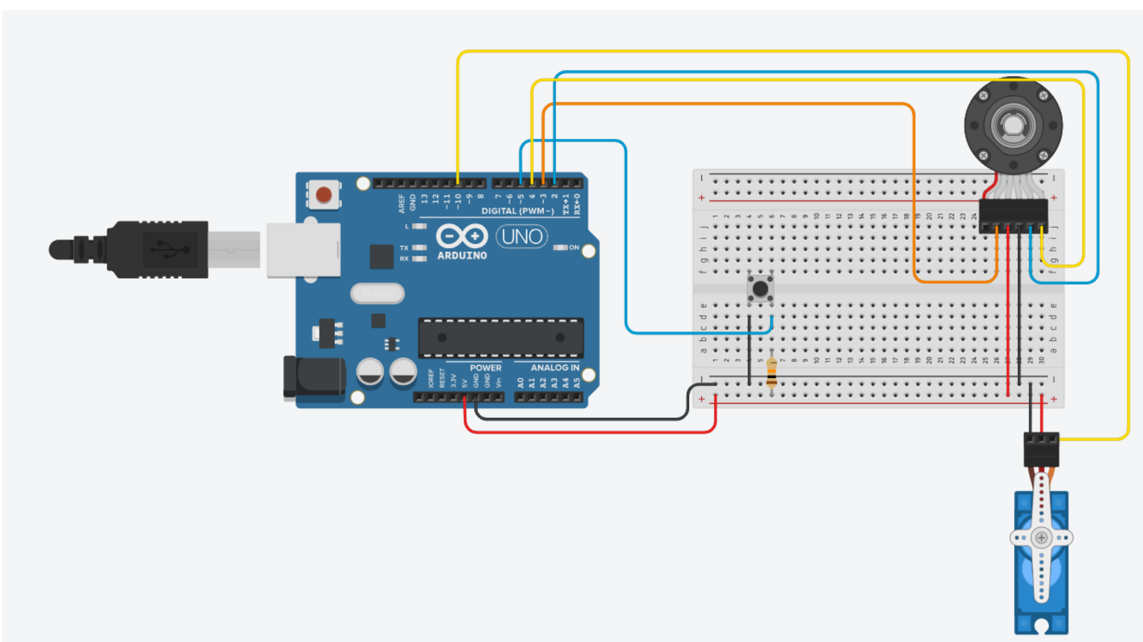
```
      if (Serial.available())
      {
        String command = Serial.readStringUntil('\n');  // Read command
from MATLAB
        command.trim();
        // once command stops being "startservo" break out
        if (command != "startservo")
        {
          digitalWrite(LEDL, LOW);
          digitalWrite(LEDR, LOW);
          break;
        }
      }
    }

    // TRACTOR SERVO
    if(command == "starttractor")
    {
      // turn on tractor button LED
      digitalWrite(LED1, HIGH);
      // wait for button press
      while (digitalRead(button1) == HIGH)
      {
        delay(20);
      }
      if (digitalRead(button1) == LOW) // Tractor button pressed
      {

        // slowly move tractor in 5 deg increments
        for (int i = 0; i <= 22; i++)
        {
          servo2.write(tmax - i*5); //tmax = 150
          delay(tdelay);
        }
      }

      Serial.println("done"); // communicate to MATLAB
      digitalWrite(LED1, LOW); // turn off button LED
      delay(5000); // wait
      servo2.write(tmax); // reset tractor to original position
    }
  }
```

APPENDIX H WIRE DIAGRAMS FOR ELECTRONICS

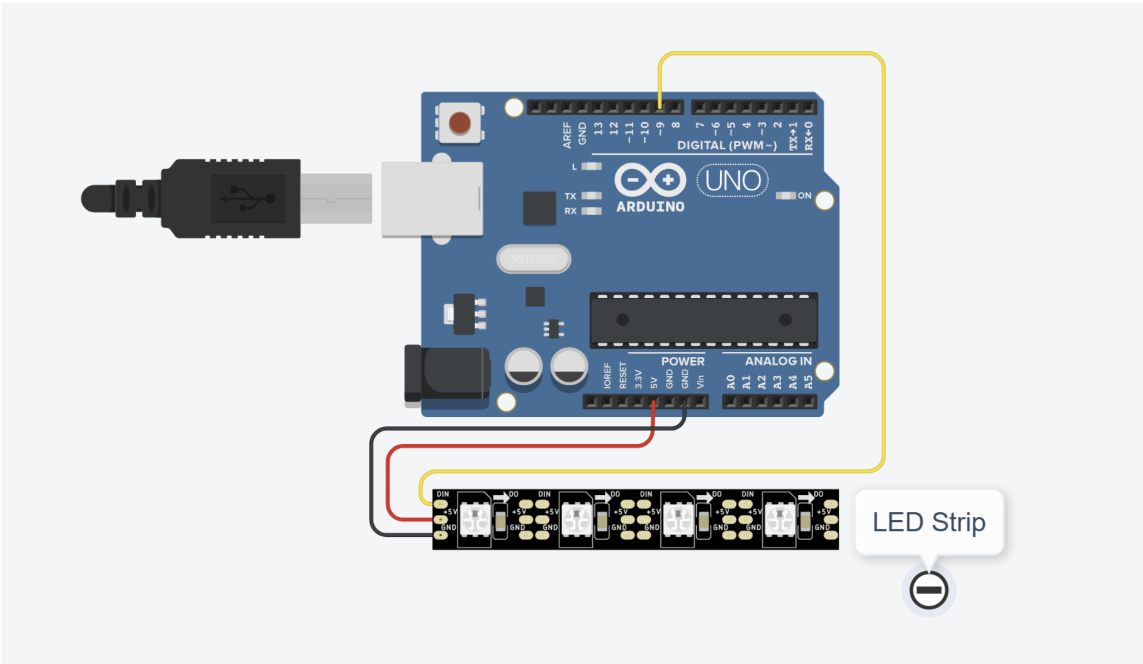
Tractor Servo Diagram:



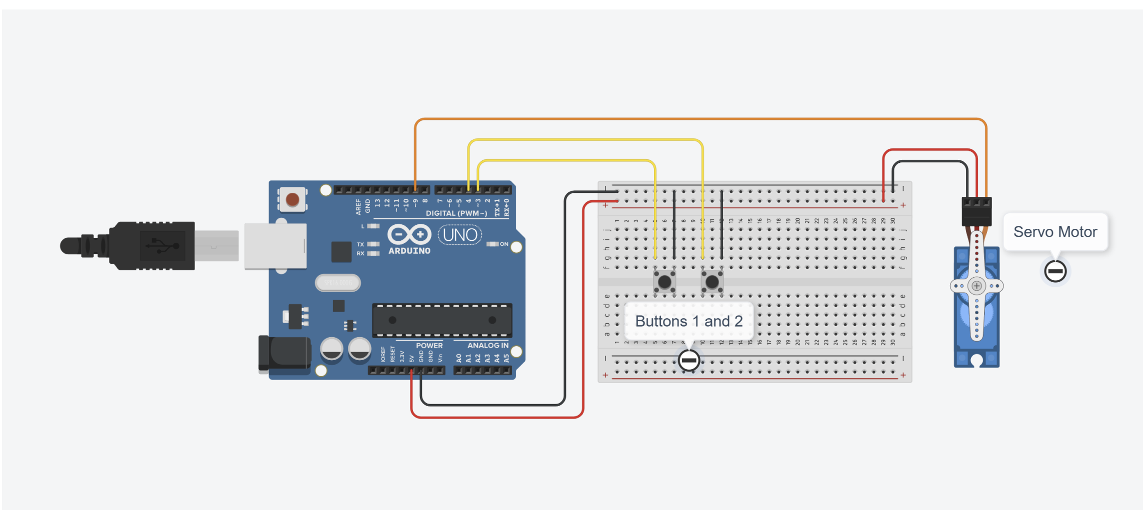
Temperature Game Diagram: Rotary Encoder Setup



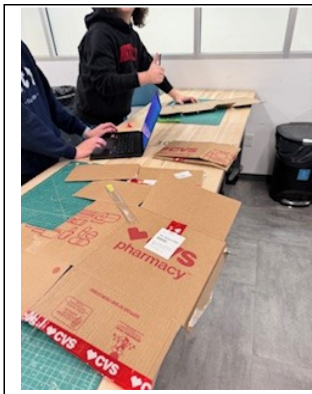
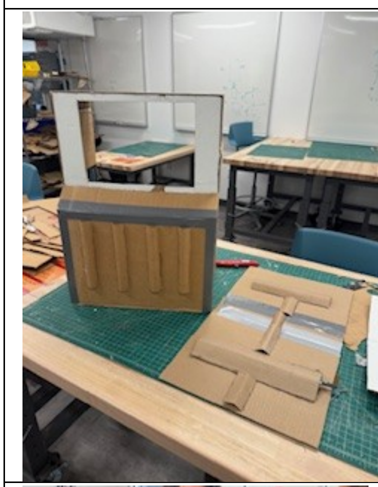
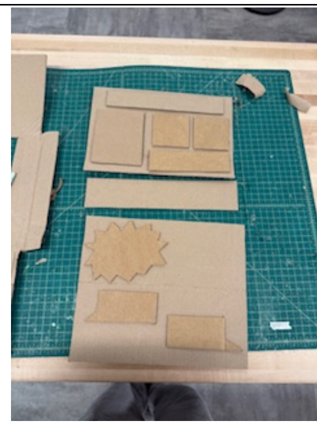
LED Strip Diagram:



Compost Collection Game Servo Diagram:



APPENDIX I PHOTO LOG

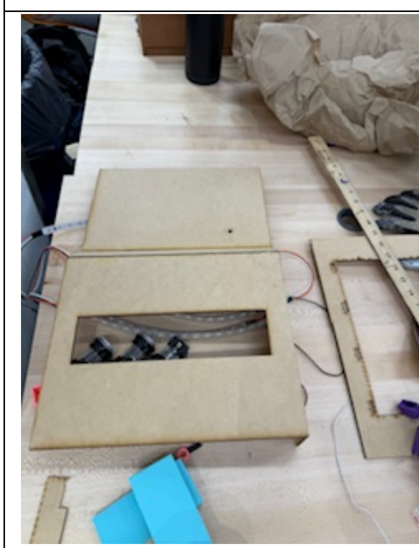
 Starting to cut cardboard	 Putting together the center panels
 Center and right panel	 Left panel
 Attaching the side panels to the center box	 Adding graphics, and color

Final Cardboard Prototype

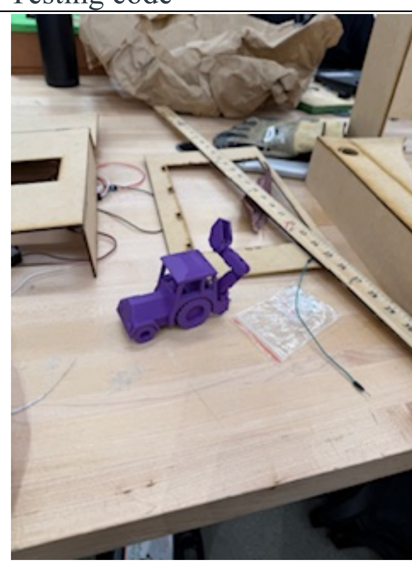
Final Cardboard Prototype

Original Infographics Panel

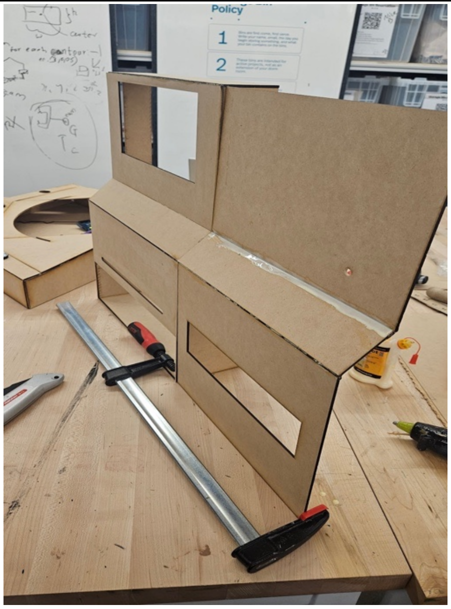
Testing code

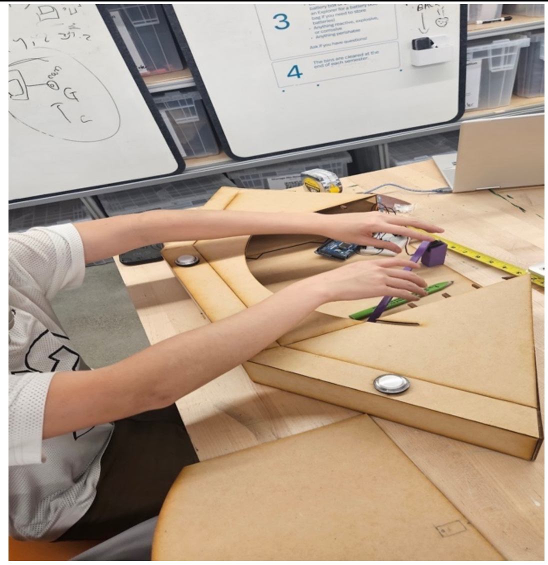


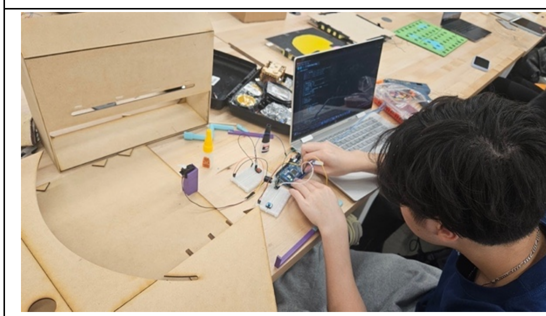
Left panel

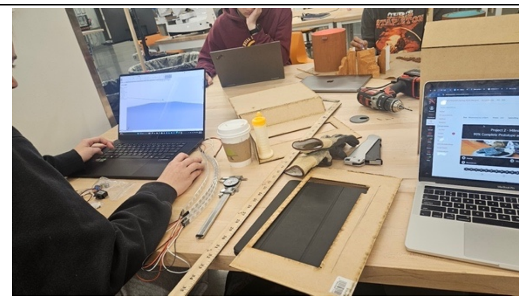


Tractor 3D Print


Attaching panels


Tractor/Servo Designing


Servo programming

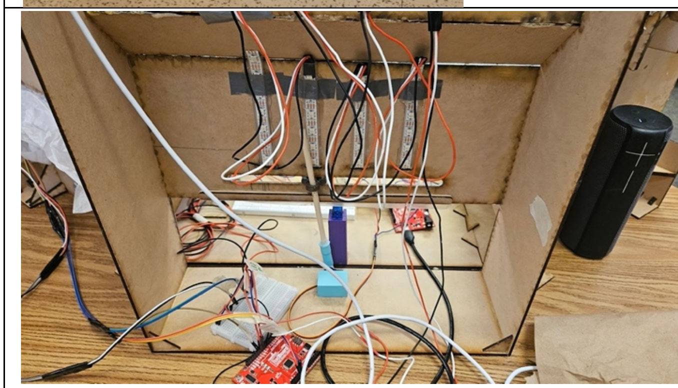

Solidworks Edits and Designing


Final- Front View


Final - Right View

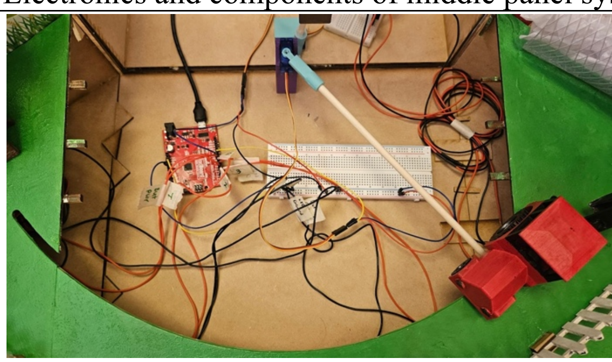
Final - Left View

Final - Front View



Electronics and components of middle panel system

Transport configuration



Inner base components and wiring

Final exhibit fully assembled in FYELIC

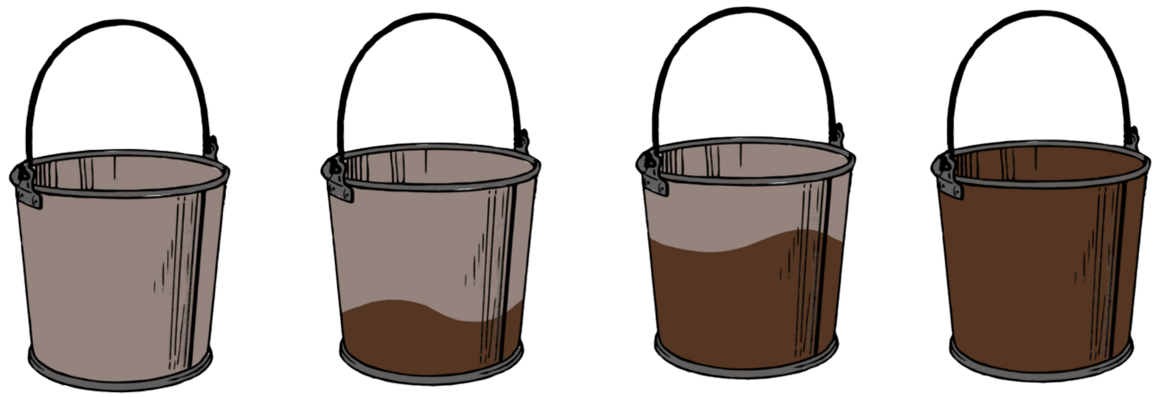
APPENDIX J GUI AND VISUAL LAYOUT

Introduction Screen

Example Layout for Compost Collection Game (too many alternative layouts)

Different Icon Options for Layout Above

Different Bucket Options for Original Layout



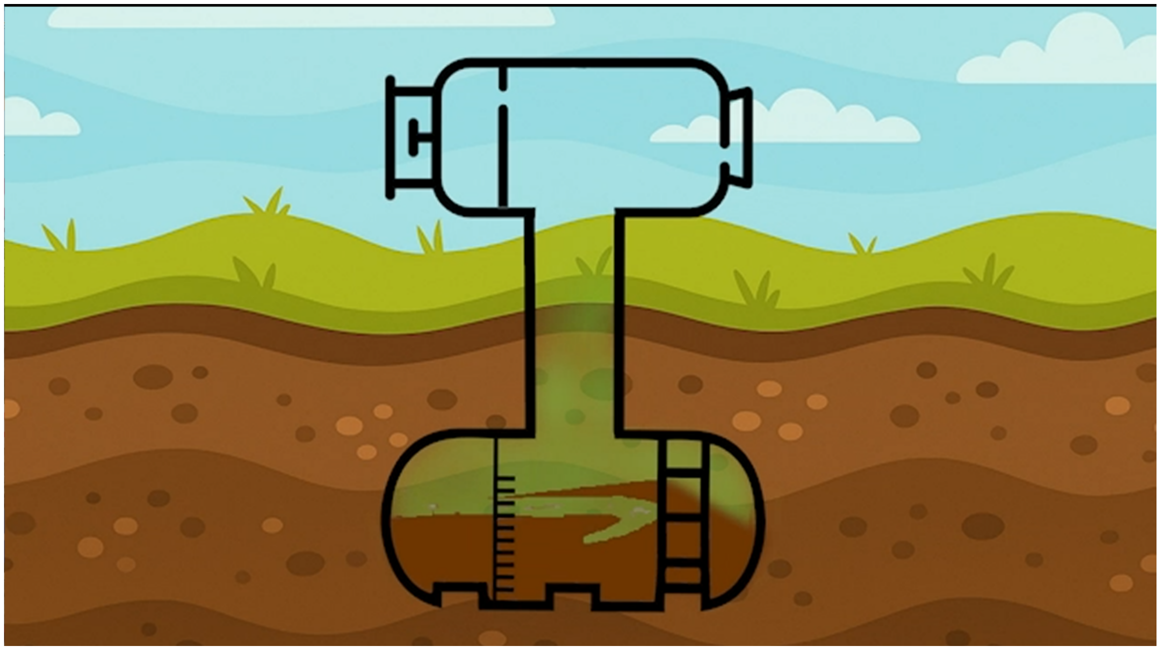
Screen Showing Collection Amount Following Compost Collection Game


YOU COLLECTED 2 BUCKETS!
That's enough for 2 Hours of Power!


YOU COLLECTED 3 BUCKETS!
That's enough for 3 Hours of Power!


YOU COLLECTED 4 BUCKETS!
That's enough for 4 Hours of Power!

Screenshot from Temperature Game Video

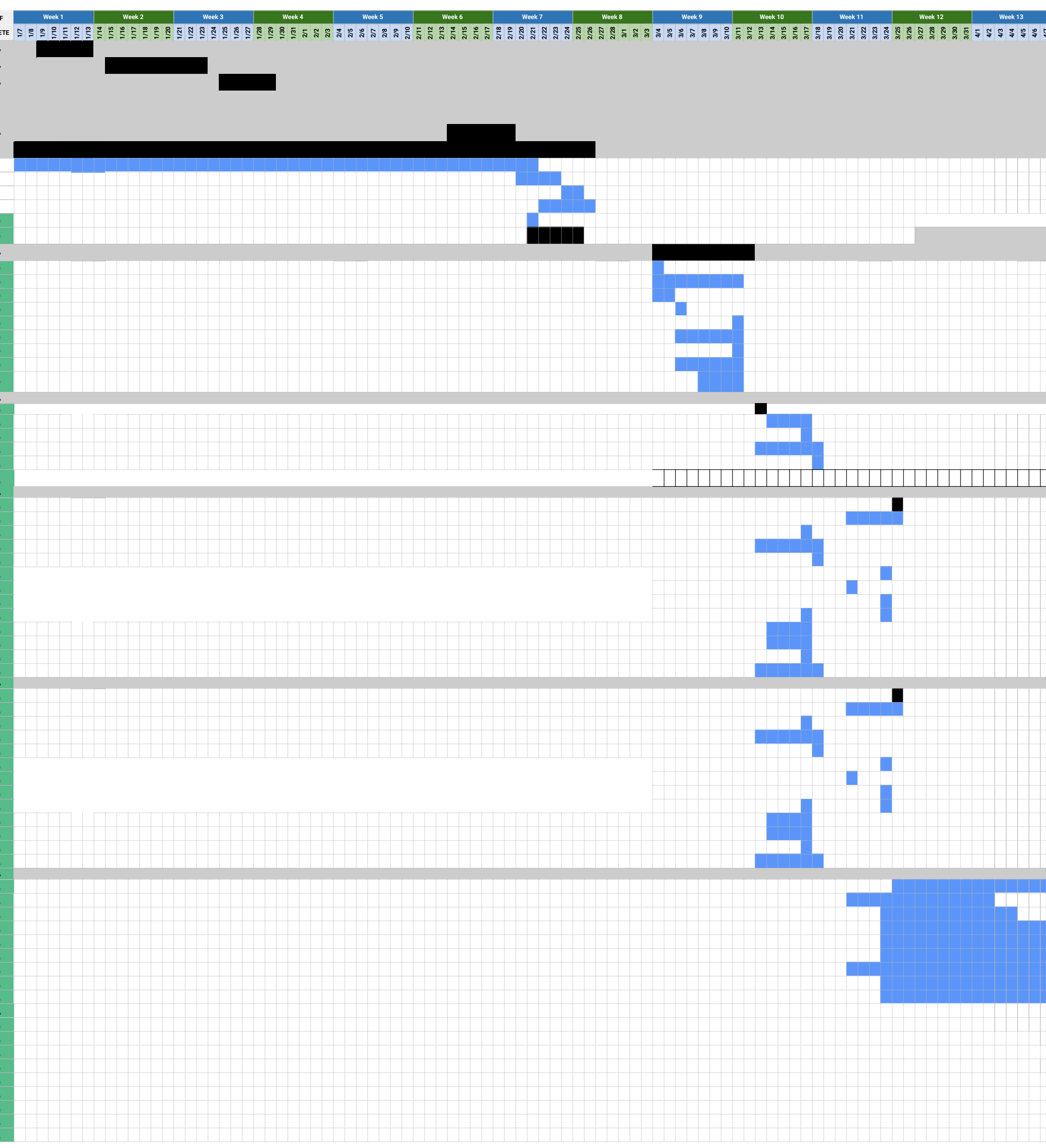


Tractor Instructions

Final Chicken Celebratory Screen

APPENDIX K FINAL GANTT CHART

	TASK OWNER	START	END	EXPECTED DURATION	PCT OF TASK COMPLETE
D2-Milestone 0	**All**	**1/9**	**1/13**		**100%**
P1-Milestone 1	**PM 1**	**1/15**	**1/23**		**100%**
P1-Milestone 2	**PM 2**	**1/25**	**1/29**		**100%**
P1-Milestone 3	**PM 3**	**1/29**	**2/10**		**0%**
P1-Milestone 4	**PM 4**	**2/10**	**2/14**		**0%**
P2-Milestone 1	**PM 1**	**2/14**	**2/19**		**100%**
P2-Milestone 2	**PM 2**	**2/21**	**2/26**		**0%**
Task 1 (Use full descriptions)	All	2/21	2/21	2hr	0%
Task 2	All	2/20	2/23	8hr	0%
Task ...	TM 4	2/24	2/25	1hr	0%
Task n	All	2/22	2/26	12hr	0%
Team Meeting #1	All	2/21	2/21	2hr	100%
Team Notebook	All	2/21	2/25	1.5hr	100%
P2-Milestone 3	**All**	**3/4**	**3/12**		**100%**
Team Meeting #1	All	3/4	3/4	2hr	100%
Team notebook	All	3/4	3/11	1.5hr	100%
Home Research/KTDA Prep	All	3/4	3/5	1hr	100%
Team Meeting #2	All	3/6	3/6	2hr	100%
Mentor Meeting #1	All	3/11	3/11	1hr	100%
CAD Drawings	All	3/6	3/11	2hr	100%
Cardboard prototype	All	3/11	3/11	4hr	100%
Status Memo	All	3/6	3/11	3hr	100%
Presentation Prep	All	3/8	3/11	2hr	100%
P2-Milestone 4	**All**	**3/13**	**3/19**		**100%**
Mentor/Team Meeting	All	3/13	3/13	2.5hr	100%
Solidworks/AutoCAD Sketches (At home)	All	3/14	3/17	3.5hr	100%
Evaluation Planning	All	3/17	3/17	0.5hr	100%
Team Notebook	All	3/13	3/18	2hr	100%
Status Memo	All	3/18	3/18	1hr	100%
Purchasing Wood + Laser Cutting	All	3/18	3/11	2hr	100%
P2-Milestone 5	**All**	**3/13**	**3/25**		**100%**
Mentor Meeting	All	3/25	3/25	0.5hr	100%
Peer Evaluation and Feedback	All	3/21	3/25	2hr	100%
Memo	All	3/17	3/17	1.5hr	100%
Presentation + Documentation	All	3/13	3/18	2hr	100%
	All	3/18	3/18	1hr	100%
Materials Run (Home Depot and FYELIC)	All	3/24	3/24	2hr	100%
Rotary Encoder Coding Demo/Research	All	3/21	3/21	2hr	100%
Tractor Servo Coding + Wiring	All	3/24	3/24	1hr	100%
3D Printing (Tractor, Stamp, Tractor L Bar)	All	3/24	3/24	3hr	100%
Tractor Servo Installation	All	3/14	3/17	2hr	100%
Temperature Game Wiring + Coding	All	3/14	3/17	3hr	100%
Crank Handle CAD	All	3/17	3/17	0.25hr	100%
3D Printing (Crank Handle)	All	3/13	3/18	1hr	100%
P2-Milestone 6	**All**	**3/13**	**3/25**		**100%**
Table of Contents Reformating	All	3/25	3/25	0.5hr	100%
Individual Sections - Introduction	All	3/21	3/25	2hr	100%
Individual Sections - Methodology	All	3/17	3/17	1.5hr	100%
Individual Sections - Background	All	3/13	3/18	2hr	100%
Individual Sections - Discussion and Analysis	All	3/18	3/18	1hr	100%
Individual Sections - Conclusion	All	3/24	3/24	2hr	100%
Individual Sections - Lessons Learned	All	3/21	3/21	2hr	100%
Group Sections - Results	All	3/24	3/24	1hr	100%
Group Sections - Final Design	All	3/24	3/24	3hr	100%
Group Sections - Appendices	All	3/14	3/17	2hr	100%
Group Sections - Table Creation	All	3/14	3/17	3hr	100%
Group Sections - Figure Inclusions	All	3/17	3/17	0.25hr	100%
Group Sections -	All	3/13	3/18	1hr	100%
P2-Milestone 7	**All**	**3/25**	**3/11**		**100%**
arduino LED matlab comm	All	3/25	4/11	0.5hr	100%
troubleshooting tractor	All	3/21	4/2	2hr	100%
laser cut and design supports	All	3/24	4/4	3hr	100%
combine led and servo in matlab	All	3/24	4/11	2hr	100%
integrate monitor	All	3/24	4/11	1hr	100%
monitor graphics (+videos)	All	3/24	4/9	2hr	100%
exhibit graphics	All	3/21	4/11	2hr	100%
tempurature game coding/calibration	All	3/24	4/11	1hr	100%
combine all parts into monitor	All	3/24	4/11	4hr	100%
P2-Milestone 8	**All**	**4/14**	**4/22**		**100%**
write introduction	All	4/14	4/22	4hr	100%
background	All	4/14	4/22	4hr	100%
methodology	All	4/14	4/22	6hr	100%
discussion	All	4/18	4/22	4hr	100%
conclusion	All	4/18	4/22	4hr	100%
recomendation	All	4/18	4/22	4hr	100%
lessons learned	All	4/18	4/22	6hr	100%
appendix images	All	4/18	4/22	4hr	100%
group sections	All	4/18	4/22	4hr	100%



APPENDIX L FINAL BUDGET

Item	Qty	Value	Cost	Source	MFR PN/Link	Notes
12"x24" Plywood sheets	3	$7.00	$21.00	Home Depot	https://www.homedepot	
12x16 Acrylic sheet	1	$12.00	$0.00	Bookstore		Pre-owned
LED Pinball Buttons	4	x	x	FYELIC		Covered by FYELIC
360 Degree Encoder	1	x	x	FYELIC		Covered by FYELIC
Arduino Mega Board	1	x	x	FYELIC		Covered by FYELIC
Servo	3	$10	$0	SparkFun Kit	https://www.sparkfun.co	SparkFun
LED (20 pack)	1	$3.95	$0.00	SparkFun Kit	LED - Assorted (20 pac	SparkFun
Jumper wires (20 pack)	1	$2.10	$0.00	SparkFun Kit	Jumper Wires - Connec	SparkFun
Redboard	1	$21.50	$0.00	SparkFun Kit	SparkFun RedBoard - P	SparkFun
Humidifier	1	$25.00	$0.00			Pre-owned
IPad Monitor	1	$279.00	$0.00	Best Buy	https://www.bestbuy.cor	Pre-owned
Vinyl Tubing	2	$8.21	$8.21	Home Depot	Everbilt 1-3/4 in. O.D. x 1-1/4 in. I.D. x 24 in. Braided V	
	Totals	$368.71	$29.21			

APPENDIX M ARDUINO PIN CHART

Base Plate Arduino:

- ☐ **0 -**
- ☐ **1 -**
- ☐ **2 - Button #1 Power**
- ☐ **3 - Button #3 Power**
- ☐ **4 - Button #2 Power**
- ☐ **5 - #1 LED Power**
- ☐ **6 - #3 LED Power**
- ☐ **7 - #2 LED Power**

- ☐ **8 -**
- ☐ **9 - Waste Game Servo Channel**
- ☐ **10 -**
- ☐ **11 - Tractor Servo Channel**
- ☐ **12 -**
- ☐ **13 -**

2nd Arduino:

- ☐ **0 -**
- ☐ **1 -**
- ☐ **2 - CLK**
- ☐ **3 - DT**
- ☐ **4 - SW**
- ☐ **5 -**
- ☐ **6 - LED Strip**
- ☐ **7 -**
- ☐ **8 -**
- ☐ **9 - Button #4 LED Power**
- ☐ **10 - Button #4 Power**
- ☐ **11 - Temp Meter Servo Channel**
- ☐ **12 -**
- ☐ **13 -**

APPENDIX N PROJECT HOURS LOG

	Caroline	Eva	Johnny	Joe	Total Work Hours
Milestone 0					
P1- Milestone 1					
P1-Milestone 2					
P1-Milestone 3					
P1-Milestone 4					
P2-Milestone 1	PM				
Individual Research	1.5	1.5	1.5	1.5	6
Team Meeting #1 (2/14)	1	1	1	1	4
Team Meeting #2 (2/18)	1	1	1	1	4
Status Memo	2	2	2	2	8
Team Notebook	1.5	1.5	1.5	1.5	6
Presentation	3.5	2	2	2	8
Totals	8	8	8	8	36
P2-Milestone 2				PM	
Team Meeting #1 (2/21)	2	2	2	2	8
Team Notebook	1.5	1.5	1.5	2	6.5
Home Research	1.5	1	1	1.5	5
Mentor Meeting #2 (2/23)	1	1	1	1	4
Status Memo	2	1	1	2	6
Presentation Prep	1	1	1	3	6
Totals	9	7.5	7.5	11.5	35.5
P2-Milestone 3		PM			
Team meeting #1 (3/4)	2	2	2	2	8
Team Notebook	1.5	1.5	1.5	1.5	6
Home Research	1	1	1	1	4
Team meeting #2 (3/6)	2	2	2	2	8
Mentor meeting (3/11)	1	1	1	1	4
Build cardboard prototype	3	3	3	3	12
Status Memo	1	1	1	1	4
Presentation Prep	1	2	1	1	5
Totals	12.5	13.5	12.5	12.5	51
P2-Milestone 4			PM		
Mentor/Team Meeting (3/13)	2.5	2.5	2.5	2.5	10
Solidworks/AutoCAD Sketches	2	4	3	3	12
Evaluation Planning	0	0	1	1	2
Team Notebook	1	1	2	2.5	6.5
Status Memo	2	1	1	2	6
Purchasing Wood/Supplies	0	0.5	0	2	2.5
Laser Cutting + 3D Printing	0	2	2	2	6
Build/Assemble Prototype	4	4	3	4	15

	Caroline	Eva	Johnny	Joe	Total Work Hours
Arduino Components + Proof of Concept	1	1	1	1	4
Presentation Prep	1.5	1	3	1	6.5
Totals	14	17	18.5	21	70.5
P2-Milestone 5					
Mentor/Team meeting (3/14	1	1	1	1	4
Storyline/Visual Development	4	1	1	2	8
Programming: Flowcharts	2	1	1	1	5
Finishing Physical Exhibit	3.5	2	3	3	11.5
Monitor Programming	0	2	2	1	5
Finish Crank Game	1	1	3	1	6
Soldering	0	3.5	0	0	3.5
Peer Evaluation/Feedback	1	1	1	1	4
Staus Memo	1.5	1	1	1	4.5
Presentation Prep	2	2	2	2	8
Laser Cutting + 3D Printing	0	1	2	2	5
Purchasing Supplies	2	0	0	0	2
Team Notebook	2	1	1	1	5
Totals	20	17.5	18	16	71.5
P2-Milestone 7					
arduino LED matlab comm	0	6	0	0.5	6.5
troubleshooting tractor	0	0	5.5	1	6.5
laser cut and design supports	0	0	0	4	4
combine led and servo in matlab	0	4	2	0	6
integrate monitor	3	4	1	0	8
monitor graphics (+videos)	9	2	0	2	13
exhibit graphics	7	1	4	2	14
tempurature game coding/calibration	0	3	6	0	9
3D Printing	0	1	3	0	4
Soldering Electronics	0	2	2	1	5
combine all parts into monitor	1	7	0	2	10
Totals	20	30	23.5	12.5	86
P2-Milestone 8					
write introduction	1	1	2	1	5
background	1	1	1	1	4
methodology	1	1.5	1	1	4.5
discussion	1	1	1	1	4
conclusion	1	0.5	2	1	4.5
recomendation	2	1	1	2	6
lessons learned	1	1	2	1	5
appendix images	2	3	2	2	9

	Caroline	Eva	Johnny	Joe	Total Work Hours
group sections	1	1	1	4	7
Totals	11	11	13	14	49
Overall Total	94.5	104.5	101	95.5	395.5