ME 450 Winter 2023
Final Report

One-of-a-Kind Tabletop Conference Display to Represent Mechanical Engineering

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Tabletop Team

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Tabletop Team | Final Report Executive Summary

Design Problem

Our project is a “One-of-a-Kind Tabletop Conference Display to Represent Mechanical Engineering.” This tabletop display will be primarily showcased at tradeshows and conferences to gather attention and assist the presenter with finding more sponsors for ME 450. Our sponsor, Eliza Austic, will be the first presenter responsible for using and maintaining the display.

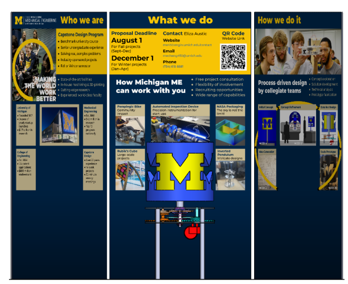
Requirements, Specifications, and Test Results

Requirement	Specification	Test Result
Legal for commercial air travel	Does not contain air-illegal substances	**Passed**
Can fit in a checked bag on commercial flights	Dimensions < 62 linear inches	**Passed**
Comfortably transported/assembled by one person	Individual Lift Weight < 21.8 lbs; Travel Weight < 50 lbs	**Passed**
Compatible with range of event tabletops	Footprint < 30” x 72”	**Passed**
Event setup needs to be reasonable	< 10 minutes assembly time	**Pending**
Can be fabricated within ME 450 budget	< $650	**Passed**
Repair needs to be reasonable	1 person needed; < 60 minute repair time	**Pending**
Repair parts or services need to be easy to find	100% off-the-shelf fasteners, in-house manufactured parts	**Passed**
Draws people into ME booth	≥ 1 lighting element, ≥ 1 brightly colored element	**Passed**
Can hold attention without presenter	≥ 1 moving element	**Passed**
Can draw and keep attention passively	100% of other aesthetic specifications are met without interaction	**Passed**
Device must run for duration of daily tradeshow presentation	> 8 hour runtime	**Failed**
The device must present no safety hazards while in operation	Tipping Force > 7.21 pounds [35]	**Pending**
Form of backdrop integrated with device	All viewing angles align with informational content	**Passed**
Demonstrates ME 450 core concept	≥ 3 previous ME 450 projects for reference	**Passed**
Appeals to forward-thinkers	≥ 1 previous socially-conscious ME 450 project for reference	**Passed**
Shows multiple stages of a design	100% of design stages shown for central device	**Passed**
Information can be updated as needed	100% of information is communicated through swappable modes	**Passed**
Branding aligns with other communications	100% of graphical elements meet Department style guidelines	**Passed**
Explains what the device is and what it does	100% of our device’s mechanical design innovations introduced	**Passed**

Engineering Analysis

Multiple rounds of prototyping, both virtual and physical, were conducted in order to make sure our device worked correctly. Packaging analysis, tipping calculations, and material selection analysis were also conducted.

Final Design Description



The selected concept was a forced perspective M that allowed us to integrate the informational aspect of the design directly with the mechanical aspect. The Beacon is a kinematic sculpture composed of two rotating halves joined by a maize-tinted, illuminated internal surface. A negative image of the Block M is revealed when observing The Beacon from any of 3 different angles around the display. The Final Design consists of many different components, namely The Beacon assembly, shaft assembly, gearbox and baseplate assembly, as well as the informational displays which align with each viewing angle.

Manufacturing Plan and Cost Analysis

Constrained by the ME 450 timeline and budget, we utilized processes that were affordable and readily available at U of M. 3D printing, laser cutting, and lathing were our main manufacturing methods.

Conclusion

Through our initial validation at the Design Expo on April 13, 2023, we received an overall positive response to The Beacon. Viewers indicated they had a positive reaction to the display, thought it reflected well on the ME department, said it would keep them engaged without a presenter, and expressed it would entice them to partner with ME 450 as a sponsor.

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ABSTRACT
The aim of this project is to create a one-of-a-kind, “wow-inducing” tabletop conference display that enthusiastically and aspirationally represents the University of Michigan Department of Mechanical Engineering undergraduate program. The main motivation for this project is to support the acquisition of new ME 450 project sponsors by drawing them into our booth at tradeshows. A high-level goal of the project is that the display gathers and keeps the attention of the audience. Additionally, the display must conform to airline product and size regulations so that the presenter is able to take it to tradeshows across the United States.

INTRODUCTION
Note: To avoid ambiguity regarding who we are speaking of, we will refer to our project sponsor as Eliza, which differentiates her from the potential ME 450 sponsors whom we are trying to attract with this project. Additionally, Eliza is the likely presenter for our project at tradeshows, and we have abstracted this role as “presenter.”

Problem Definition
Project 8 is a “One-of-a-Kind Tabletop Conference Display to Represent the University of Michigan Mechanical Engineering Department.” This tabletop display will be showcased at tradeshows and conferences across the United States. Additionally, our display may be used at U of M outreach events or college fairs. Our project sponsor is Eliza Austic, the ME 450 course coordinator. Eliza will also likely be the primary booth presenter at the aforementioned tradeshows.

Through our interviews with Eliza [1], research on the project, and overall understanding of the project goals, we have developed a problem statement which is defined as follows: “The University of Michigan Mechanical Engineering Department does not have a tabletop display to gather attention and showcase its capabilities at tradeshows and conferences. We need to create a "wow-inducing" display that attracts industry engineers and management to our booth, conveys information about ME 450, and drives engagement with the ME department. The end goal of this engagement is to draw positive attention to the program, not just as an educational endeavor, but also as an accessible design resource for public and private entities.”

From this, and from our conversations with Eliza [1], we have derived that our main motivation as to why this project exists is to support finding new ME 450 project sponsors. A secondary motivation is to gain interest from potential donors who would like to earmark more general donations to the University. A tertiary motivation is to gain interest from potential students and faculty. The overarching motivation for all of this is to provide outreach for the ME Department in general and the ME 450 program in particular. This is an important problem to solve because the ME department has seen a drop off in recent years in terms of exciting new sponsors for our capstone projects; thus, we need to improve our marketing strategy. Eliza has confirmed the current table setup at these tradeshows consists of “swag” giveaways, i.e. T-shirts, bracelets, pens, etc. From this, we can infer that our design problem hasn’t been solved.

The major objectives and goals of our project are to create an eye-catching display that draws potential sponsors to our booth, such that our booth presenter can initiate a conversation with them about the benefits of partnering with ME 450. To aid this engagement, our display also includes an informational backdrop that provides background on the program, explains the process of partnering with ME 450, and demonstrates the design process for our display. A repair manual for the display will be provided as well. A successful project outcome will be measured by the number of new sponsors we attract compared to the number of new sponsors we were attracting before implementing our tabletop display.

There has been no previous work done by our sponsor or others regarding a tabletop display for tradeshows. Previous solutions did not incorporate a "wow-inducing" display at the tradeshow booth.

Stakeholder Analysis

Our two main groups of stakeholders are the presenter, who will be running the ME booth at tradeshows, and the viewers, who we aim to attract to the booth. Consideration must also be given for maintenance, some of which may be performed by the presenter, but much of which may have to be outsourced to dedicated firms or on-campus specialists. Additionally, because our display will represent the ME department, the perspectives of people within the department must be conveyed. In particular, we need to represent the organizing faculty's vision for the course. All of these stakeholders' perspectives are important to consider, but the main people we are designing for are the viewers of our display and its operator.

In its primary application, our display will be viewed mainly by potential corporate ME 450 sponsors, as those are the people who tend to be at tradeshows. There may be some potential donors to the university and potential non-profit project sponsors in attendance, as well, but they are likely to be significantly outnumbered by corporations. Secondary applications, though, such as display at more UM-focused outreach events or semi-permanently on campus, may provide additional avenues for reaching these viewers. These secondary applications may also allow us to reach potential students and faculty for the University and professors who might sponsor projects. Overall, though, our primary audience consists largely of potential corporate sponsors. We consider CEOs to be of higher importance than rank-and-file engineers for this purpose, simply because appealing to them directly rather than going up the chain of command will allow us a better chance at obtaining the desired support.

Of these corporations, we are particularly interested in appealing to start-ups. The smaller scale of these firms can make an ME 450 project more appealing to them, on account of its lower cost than traditional engineering consulting services. Additionally, we are especially keen to attract forward-thinking firms with regard to environmentalism and inclusivity, and the relative youth of start-ups tends to match these ideals more. In service of appealing to this audience, we obtained the contact information of a current sponsor meeting these criteria and conducted an interview to better understand his perspective. We have summarized the relations of these parties in the diagram seen in Figure 1.

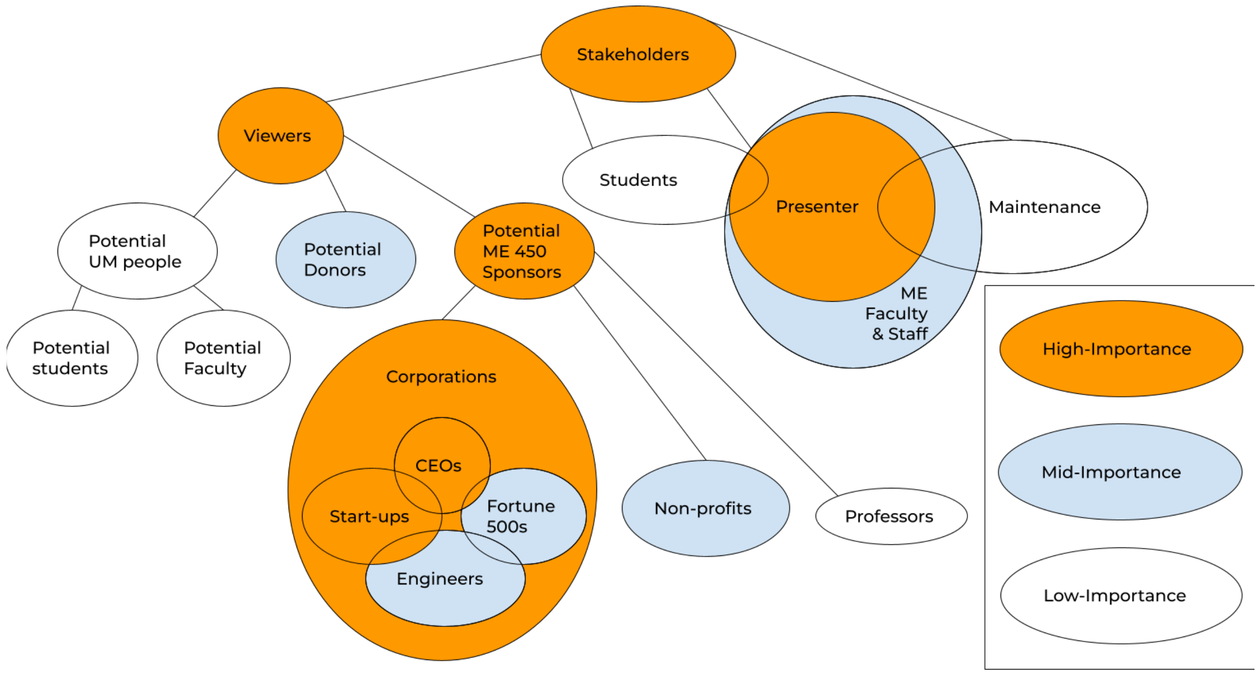


Figure 1. A stakeholder map, showing a breakdown of the direct stakeholders of this project, along with some indirect stakeholders. Overlapping bubbles represent the possibility for a single person or group to fall within multiple categories.

Through direct interactions with some of these stakeholders, we have been able to gain a clearer understanding of their perspectives of this project. Throughout the design process, we have been working closely with presenter Eliza Austic (who is also the sponsor of our project), and her needs for our display form the backbone of our design goals. We have also conducted interviews with several other stakeholders: Existing sponsor Mike Carovillano of Vayu Aerospace has helped us better understand the perspective of the start-ups we hope to attract, emphasizing extreme concision of information and a strong focus on "wow-factor." ME Communications director Makenzie Schlessman has given input on voice, messaging, and style used in our public-facing communications, emphasizing professionalism in design and intentionality in messaging. Course organizing professor Steve Skerlos has clarified the pedagogical vision of ME 450 and provided valuable insight into the relationship between the course and its sponsors, emphasizing the value of fresh perspectives and a holistic approach to design.

Design Process

The design process for our central display follows a pair of main stages: Conceptual exploration and solution development. The first stage encompasses the tasks needed to fully understand the problem and develop a concept for a solution. The second comprises the creation, verification, and iteration of a refined design of that general concept. Within each stage, we followed a different model for our activities. In the first, we explored in a very fluid manner, owing to the open-ended nature of our problem. In the second, we followed a more traditional approach, iterating the development of our design through verification. [2]

Building off our knowledge of design in general and our project in particular, we have holistically developed a design process, which has been analyzed to produce the descriptive model shown in Figure 2. This model consists of three primary divisions: The main design process used to create the central device of our display, the design process used to create an informational backdrop display, and the design process used to create the repair manual to go with our device. [2]

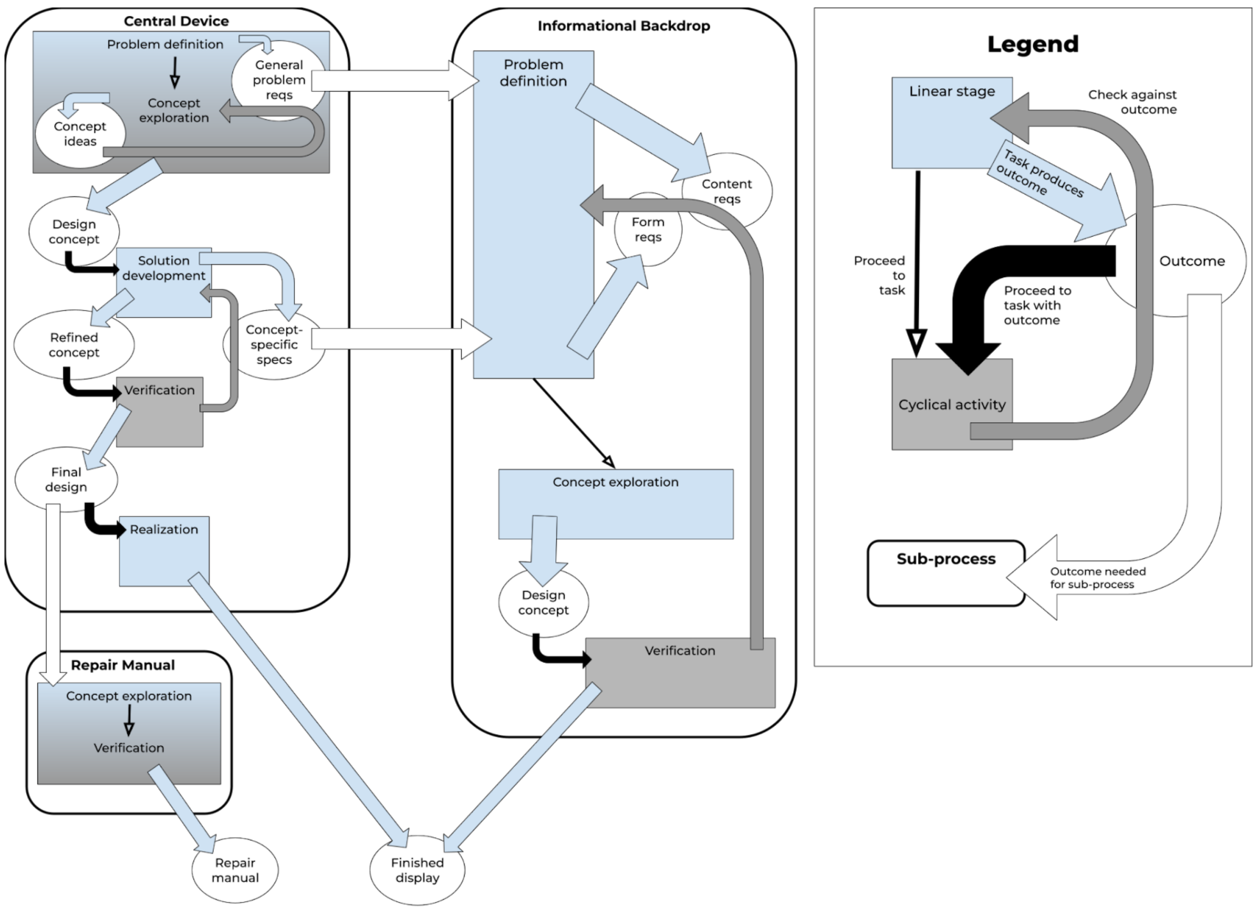


Figure 2. An image showing the design process we are using for our project. Rectangles indicate tasks, and bubbles indicate outcomes. Blue fill indicates a linear progression, and gray fill indicates iterative activities.

To produce the central device, we started with problem definition, which produced general requirements and specifications, and gradually transitioned to concept exploration, which produced initial ideas. We checked these ideas against those general requirements, and we iterated problem definition and concept generation. This process selected a single design concept, with which we proceeded to solution development. This task produced concept refinements and concept-specific requirements and specifications. We took this refined concept and proceeded with it into verification, where it was checked against those specifications. We iterated these activities and produced a fully-specified design, with which we proceeded to realization, producing a finished display.

The sub-processes used to create our two secondary deliverables required our primary design to have reached certain degrees of completion in order for us to understand the display well enough to complete them, so they began later in the semester and ran in parallel with the main one.

We divided the problem definition of our informational backdrop into two parts: The content that must be displayed and the form of its display. These each have their own requirements, the former dictated by the general project needs and the latter more closely tied to the specifics of the central display. We used a smaller process of iterated concept exploration and verification to produce a final design for the informational backdrop, from which we realized the physical display. Because much of the verification of this component consisted of stakeholder feedback, we had to repeat problem definition with each iteration, rather than just concept exploration.

The process used to develop the repair manual does not have dedicated stages for concept exploration and verification, on account of the limited time we had left after the final design of the central device was completed and the difficulty of testing repair processes for a brand-new device. Understanding that we cannot predict all repairs that may be necessary, the repair manual is simply a thorough list of the processes used to create the device, completed in tandem with the assembly instructions and without a complicated, multi-stage process.

The most significant difference from the traditional ME 450 design process is that we are carrying our project all the way to realization, not stopping at solution verification. This is possible due to the small scope of our project. Additionally, because our problem is extremely open-ended, there is a significant blurring between the problem definition and concept exploration stages. We began informal concept exploration very early on in our design process, before we had a fully-formed understanding of our design problem, and we made significant changes to our requirements and specifications after we had a concept selected. While the ME 450 standard design process does call for repeated iteration between stages, our process differs in treating these two activities as effectively a single, fluid stage, with tasks performed not just cyclically be simultaneously. [2]

Because this project is very open-ended, the various tasks in the design process do not follow a clear linear progression, with the outcomes of each task affecting the details of the others. As a result, this project is best suited by a primarily activity-based design process; an exclusively stage-based process would be too creatively limiting. For similar reasons, our project is best suited by a solution-focused design process; a problem-focused process does not naturally fit a problem with such a heavy emphasis on concept generation. Because of the bespoke nature of our design problem, our project requires a procedural approach to designing. While Wynn &

Clarkson [3] assert that procedural approaches must be problem-oriented and thus are always stage-based, we feel that by applying a descriptive model for this unconventional design problem, we can see how our design process does not follow that framework. We have project-specific procedures that we are following, so our design process is not abstracted for general use, but these procedures are too fluid to accurately be described as problem-oriented or fully stage-based. Instead, our particular case is best suited by a project-focused model of a procedural yet solution-oriented approach.

Research and Information Sources

Throughout our work on this project, one of our most valuable sources of information has been direct interaction with stakeholders. We have conducted interviews with our presenter [1], an existing ME 450 project sponsor representing a start-up [4], the ME Department Communications director [5], and the ME 450 organizing professor [6]. Through these conversations, we have gained an understanding of these stakeholders' visions for this course as an opportunity for students, clients, and the University.

Further research was necessary to determine the most effective way to convey this perspective within the constraints of our project. Thus, information sources were acquired using databases accessible through the University of Michigan Library, such as Scopus, IEEE, and ISO. Google Scholar was also used as a resource to find credible information.

Background Information

In order for us to understand how to create an eye-catching, "wow-inducing" display, we did some academic research on what makes a good tabletop display, window shopping psychology, and advertising.

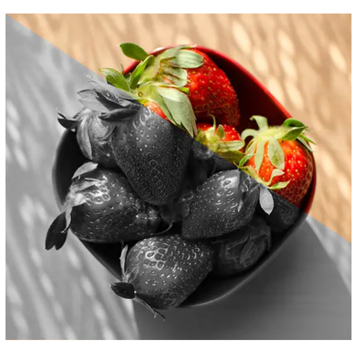
Starting off with what makes a good tabletop display, the most prominent thing we learned is that it is important for your display to be interactive [7, 8, 9]. This is because if the display is interactive, then someone will be standing by your booth interacting with your display, others will notice and crowd around, and this effect will compound on itself until your booth is popular with high traffic. We also learned that good lighting is important, such that the audience can see everything clearly [7, 10]. In terms of which colors are most effective, studies show that viewers see the color blue as trustworthy, secure, and dependable [11, 12]. This is why you see brands like Twitter, Windows, and Disney+ using blue for their logos (see Fig. 3a). Finally, it is important that your call to action contrasts your primary color well, and you can do this by using the color opposite it on the color wheel, as shown in Figure 3b [11].

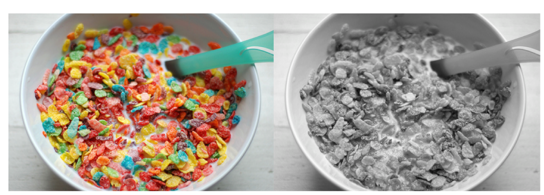
(a) (b)

Figure 3. (a) Many successful companies use blue for their logos as it is associated with trustworthiness, dependability, and security [9]. (b) The color wheel should be used for contrasting your call to action [13].

Moving on to our takeaways from our window shopping research, again we found that interactive displays work well at drawing the customers' attention [14]. In relation to visual stimuli that are used, stores use different color-coordination through different seasons and holidays (red near Valentine's Day, orange near Halloween, etc.); this engages with the customer and draws them in as well. Customers in these studies also noted that proper lighting was important to see the display clearly. These same customers also noted that bright colors stand out and catch their eye. Studies also show that it is critical for main points to be centralized in the display, and that eccentric, uncommon, or memorable displays entice customers better than unoriginal displays [14, 15].

Additionally, our research in advertising in relation to our project allowed us to learn that colored images do a much better job of enticing viewers than grayscale images [16]. A great example of this is depicted in Figure 4a, with a picture of strawberries, and in Figure 4b, with a picture of Fruity Pebbles.





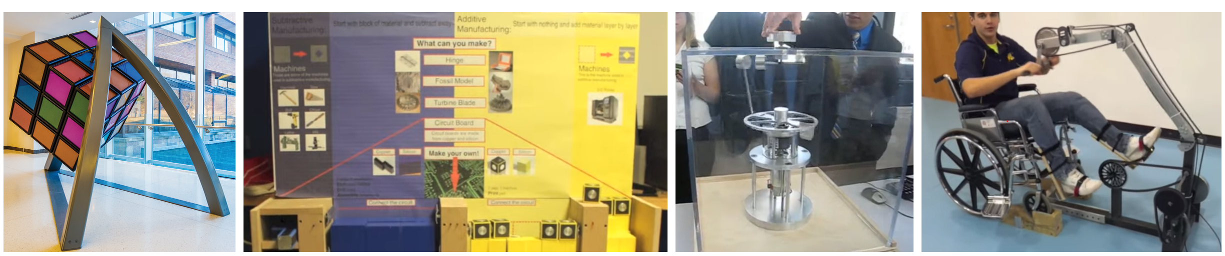
(a) (b)

Figure 4. Advertising images in color versus grayscale. Clearly, the (a) red strawberries [17] and (b) colorful Fruity Pebbles [18] entice the customer to buy the products more than the grayscale images.

Since this initial research, we have mostly focused on more active designing, but continued research has still produced important results. Because our display (described in more detail later) relies on visual perspective to resolve into a meaningful image, it is paramount that its height and size are ideal for viewing. To ensure this is the case, we have researched ideal viewing angles, finding that the typical field of view is within 30º in either direction of eye level [19]. For a person standing 30 inches (the standard tradeshow table depth [20]) from an object, this equates to a vertical size of under 33 inches. For someone with an eye level of 62 inches (typical for US adults [21]), this equates to the centerpoint of the object being approximately 32 inches above the standard 30-inch-high table [20]. This perspective research has driven the refinement of our design solution to best meet the needs of our design problem.

Benchmarking

Our research also extends into the topic of benchmarking. Our primary source of inspiration for our benchmarking was previous ME 450 projects. Based on our interviews with Eliza [1], we determined that it was crucial that our display show what ME 450 students are capable of so that we can advertise the quality of work the potential ME 450 sponsors could receive through partnering with ME 450. We reviewed past successful large-scale projects like the giant Rubik's cube display, along with those that represent a variety of mechanical disciplines and intricate mechanical design, such as the additive and subtractive manufacturing display and the inverted pendulum. The latter two projects have been in the Ann Arbor Hands-On Museum as interactive exhibits, as well. Eliza has also noted that the ME Department would like to attract new sponsors that are forward-thinking, innovative, or work for the community good. Thus, we can review and advertise a past project like the paraplegic exercise bicycle. Figure 5 showcases all of these past projects.



(a) (b) (c) (d)

Figure 5. Past successful ME 450 projects. (a) Giant Rubik's cube [22], (b) additive and subtractive manufacturing display [20], (c) inverted pendulum [23], (d) paraplegic exercise bicycle [24].

For comparison of our ME Capstone program with other universities, we can compare to Michigan State University, which offers a similar program with an equivalent sponsorship fee of $5,000 [25]. Comparing to Clemson University, their sponsorship costs $10,000, but here, three or four teams approach the same design problem, so the sponsor is given different solutions for their project [26]. Penn State University offers a similar program to be completed in the campus's hands-on design center, the Learning Factory [27]. Overall, all of these programs advertise the experience by reminding the companies that they get to work with great students on tough problems while building relationships and improving name recognition on campus. To differentiate our program, it is important to emphasize not just that educational function but also the direct benefit to the sponsors: Quality engineering work at a fraction of the cost of traditional consulting firms.

In addition to benchmarking the display itself and the broader ME 450 program, we also need to look at packaging for travel. For reference, common large protective travel cases retail for well over $400 [28], which would likely be an unreasonable expense for our project. However, looking at the materials used for protection, a polypropylene shell with polyurethane foam is typical, and the latter in particular could likely be directly procured and custom-installed in an existing case for a significantly reduced cost while maintaining most of the functionality.

Additionally, through an interview with an experienced tradeshow presenter and business traveller [29], we determined that existing tri-fold poster displays will not fit in an airline-compliant suitcase.

Regulations and Standards

After talking with Eliza and understanding the general idea of what she expects, we believe that there are two sets of regulations to consider with our project. Eliza wants a tabletop display that will be handled primarily by one presenter and occasionally with another person as they fly across the country to tradeshows and other conventions doing outreach for ME 450. Based on the product that Eliza wants delivered, we can extrapolate that the display we create must be able to be lifted by one presenter while they are working on behalf of the University of Michigan and go through commercial air travel in the United States. Ergo, Occupational Safety and Health Administration standards must be upheld and Transportation Security Administration guidelines must be followed.

OSHA is a regulatory agency that enforces labor safety laws across the United States. Much of what they enforce is derived from research that is conducted at NIOSH, the National Institute for Occupational Safety and Health. NIOSH has an application manual that explains a “Lifting Equation” that calculates the ratio of how much an object weighs to a recommended weight limit. This Lifting Equation is presented below as Equation 1 and can be rearranged to form Equation 2.

$$\mathrm{LI} = \frac{L}{RWL} \quad (1)[30]$$

$$\mathrm{L} = \mathrm{LI} \times \mathrm{RWL} \quad (2)[30]$$

L is the load weight, or the weight of our display, LI is the lifting index, and RWL is the recommended weight limit. The RWL can be found in Equation 3 as:

$$\mathrm{RWL} = \mathrm{LC} \times \mathrm{HM} \times \mathrm{VM} \times \mathrm{DM} \times \mathrm{AM} \times \mathrm{FM} \times \mathrm{CM} \quad (3)[30]$$

Here, LC is the load constant which is given in the manual as 51 lbs, HM is the horizontal multiplier and is defined in Equation 4, VM is the vertical multiplier and is defined in Equation 5, DM is the distance multiplier and is defined in Equation 6, AM is the asymmetric multiplier and is defined in Equation 7, FM is the frequency multiplier and can be found in Figure 6, and CM is the coupling multiplier and can be found in Figure 7.

$$HM = \frac{10}{H} \quad (4)[30]$$

$$VM = 1 - (0.0075|V-30|) \quad (5)[30]$$

$$DM = 0.82 + \frac{1.8}{D} \quad (6)[30]$$

$$AM = 1 - (0.0032A) \quad (7)[30]$$

Standing upright, holding the object at the highest point of the lifting action, H is the horizontal distance between the projection point of where one's center ankle bones meet and the projection of the center of the object, V is the vertical distance between the ground and one's hands, D is the distance between the hand position when starting the lift and finishing the lift, and A is the angle one has to turn to complete the lift. Coupling type was derived from Figure 8. Drawn dimensions for H, V, and A can be seen in Figure 9.

Frequency Lifts/min (F)‡	Work Duration					
	≤1 Hour		>1 but ≤2 Hours		>2 but ≤8 Hours	
	V<30†	V≥30	V<30	V≥30	V<30	V≥30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

†Values of V are in inches.
‡For lifting less frequently than once per 5 minutes, set F=.2 lifts/minute.

Figure 6. This figure demonstrates how to obtain FM from F, the number of lifts per minute, and from V, the vertical distance between the ground and one's hands when holding an object at the highest point of a lifting action [30].

Coupling Type	Coupling Multiplier	
	V<30 inches (75 cm)	V≥30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Figure 7. This figure demonstrates how to obtain CM from the coupling type and V [30].

	Good	Fair	Poor
Containers (i.e. boxes, crates, etc.)	Handles or handhold cutouts of optimal design [see notes 1 to 3 below]	Handles or handhold cutouts of less than optimal design [see notes 1 to 4 below]	Less than optimal design, loose parts, or irregular (i.e. bulky, hard to handle, sharp edges) [see note 5 below]
Loose parts or irregular objects (i.e. castings, stock, and supply materials)	Comfortable grip (i.e. hand can easily wrap around the object) [see note 6 below].	Grip in which hand can flex about 90 degrees [see note 4 below].	Non-rigid bags (i.e. bags that sag in the middle)

1. An optimal handle design has .75 – 1.5 inches (1.9 to 3.8 cm) diameter, ≥4.5 inches (11.5 cm) length, 2 inches (5 cm) clearance, cylindrical shape, and a smooth non-slip surface.
2. An optimal hand-hold cut-out has the following approximate characteristics: ≥ 1.5 inches (3.8 cm) height, 4.5 inches (11.5 cm) length, semi-oval shape, ≥ 2 inches (5 cm) clearance, smooth non-slip surface, and ≥ 0.25 inches (0.60 cm) container thickness (e.g., double thickness cardboard).
3. An optimal container design has ≤16 inches (40 cm) frontal length, ≤12 inches (30 cm) height and a smooth, non-slip surface.
4. A worker should be capable of clamping the fingers at nearly 90° under the container, such as required when lifting a cardboard box from the floor.
5. A container is considered less than optimal if it has a frontal length >16 inches (40 cm), height >12 inches (30 cm), rough or slippery surfaces, sharp edges, asymmetric center of mass, unstable contents, or requires the use of gloves. A loose object is considered bulky if the load cannot easily be balanced between the hand-grasps.
6. A worker should be able to comfortably wrap the hand around the object without causing excessive wrist deviations or awkward postures, and the grip should not require excessive force.

Figure 8. This figure explains how to determine a container's coupling type, which is useful for the previous figure [30].

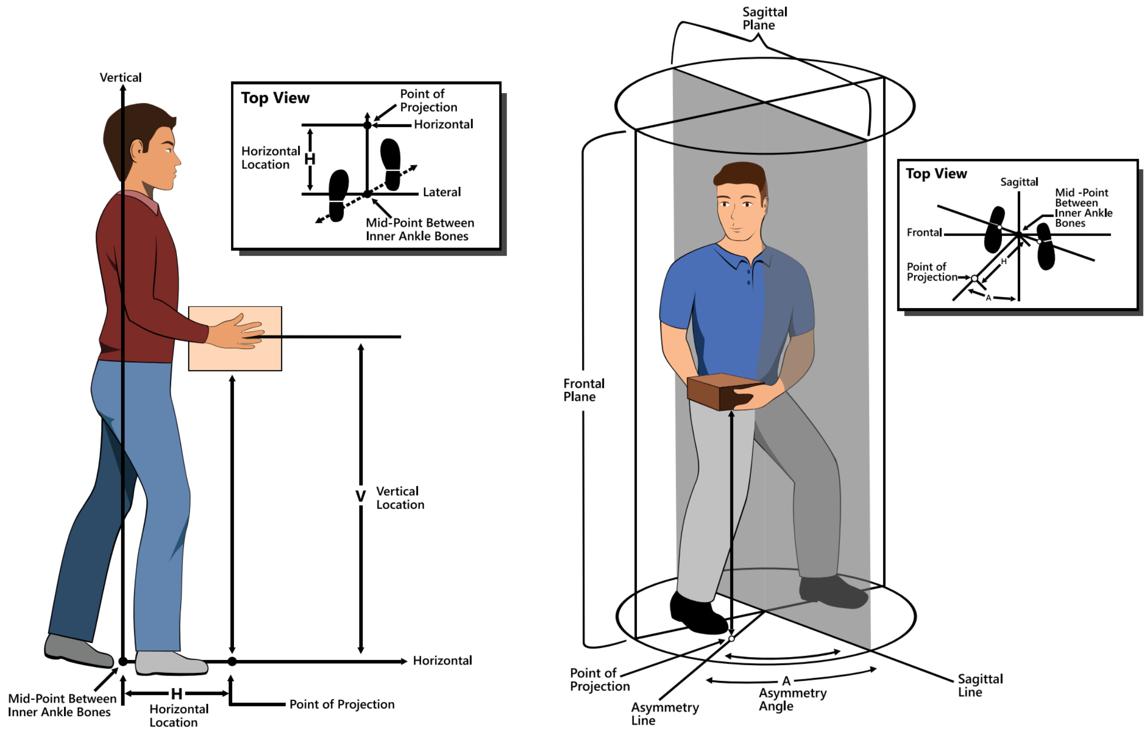


Figure 9. The figure above shows how the dimensions H, V, and A are measured [30].

To determine the maximum allowable load weight L for our presenter to safely lift, LI was set to its maximum value of 1, we used a bin size of 28 ╳ 18 ╳ 10 inches (which is allowable for checked luggage, as shown below), and used Equations 1-7 and Figures 6-9. To determine the values of the dimensions, we estimated our presenter's measurements using 5th percentile average data for women in the United States [21]. All of the values used for these calculations can be found in Table 1.

Table 1. This table shows the load weight L, or the maximum weight our presenter should lift, along with all of the values needed to determine it.

H	**12 in**	HM	**0.83**
V	**40 in**	VM	**0.925**
D	**35 in**	DM	**0.87**
A	**90°**	AM	**0.71**
F	**2 lifts/day = 0.0014 lifts/min**	FM	**1.00**
Coupling Type	**Poor**	CM	**0.90**
LC	**51 lbs**	RWL	**21.78 lbs**
LI	**1**	L	**21.78 lbs**

Eliza stated that the plan for traveling with the display we create will be to have it in a container that is checked at the airport. This means that we must consider guidelines enforced by the TSA. The current list of items the TSA has on their website for commercial air travel clarification is 491 items long, so a link to the complete comprehensive list can be found in reference [31]. Some potential items that we could have used that no longer are available to us include spare lithium batteries, flammable liquids, canned oxygen, and electric lighters [32]. The conditions of where the luggage goes on a plane, along with the altitude and pressure of the plane, are not ideal for these items. The idea is that they, and many other items that cannot go in checked bags, may contribute to the potential danger of combustion, whether it is the item itself combusting or aiding the combustion of something else.

Not being allowed to bring spare lithium batteries limits the number of potential power sources we can pick to operate our display. Flammable liquids, canned oxygen, and electric lighters are all ways of aiding or starting a fire which could potentially be a good idea for drawing attention towards our display. However, we have had to plan on not using fire due to these items no longer being an option for us. Fire also, of course, potentially poses a danger to the people near the display, so it likely would not have been feasible anyway.

In order to create a great tabletop display, it is important that we are able to fit the display on standard tradeshow tables, which are between 6 and 8 feet long and are 30 inches deep [20]. In addition to the tradeshow dimensions, we must also take into account airline baggage restrictions. Most airlines have standardized checked bags to be less than 62 linear inches (length + width + height) and restrict the weight to be less than 50 pounds [33]. Other targeted research to aid in defining engineering specifications for our user requirements is described in further detail in the “Requirements and Engineering Specifications” section.

Intellectual Property

Due to the unique nature of this display, we have been able to make decisions that intentionally avoid the use of patented ideas, circumventing potential costs associated with licensing. On the other hand, there is a good chance that the end result will be patentable and/or copyrightable (as we will be creating what is essentially a piece of art) in our names. However, no intellectual property or non-disclosure agreement was signed for this project. Since our project will be used directly by the ME department, we believe all intellectual property will be shared between our team members and the ME department.

REQUIREMENTS AND ENGINEERING SPECIFICATIONS

The solution-space of this project is fundamentally very open. To aid the selection of an optimal concept, we outlined some requirements and specifications our solution must meet in order to close scope. In the context of this project, requirements are expectations held by the sponsor, Eliza, regarding different qualities of the solution. Specifications are our team’s translation of those expectations into measurable design details. The process for specification development was systemic, as seen in Figure 10.

Figure 10. Specification Design Process.

The beginning of the process was our first conversation with the project sponsor. Notes from this and later conversations were compiled into requirements that define what she expects the product to do for her. Then, we connected requirements to our researched background information and developed a quantified specification based on the intent of the task. Finally, this specification was reviewed with our sponsor and verified to be measurable. Specifications with negative feedback were reworked until all specifications were aligned with the project sponsor's needs.

Interviewing Eliza to explore her interaction with the solution, and thus the interaction of future presenters, is the critical start to our specification design process. Our notes and their subsequent requirements may be found in Table 2.

Table 2. Conversation notes and requirements.

Sponsor Conversation Solution Notes	**Requirement**
Transported by single presenter	Comfortably transported/assembled by one person
Needs to be transportable by plane	Passes applicable regulations for commercial air travel
	Can fit in a checked bag on commercial flights
Events are often crowded, with attendees getting sharing tight space with displays	The device must present no safety hazards while in operation
Setup and packed on daily basis	Event setup needs to be reasonable
Goes to events all over the US	Compatible with range of event tabletops
Presenter interacts with people all day	Device must run for durations of daily tradeshow presentation
Wants ease of repair	Repair needs to be reasonable
Minimal effort to maintain	Repair parts or services need to be easy to find
Very little funding for outreach	Can be fabricated within the ME 450 project budget
Wants display to start conversations	Draws people into ME booth
Display can entertain indirect audience	Can keep a person's attention while presenter talks to someone else
No direct interaction needed to draw attention	Can draw and keep attention passively
Wants synergy between central device and informational backdrop	Form of backdrop integrated with device
Needs to represent the department	Branding aligns with other communications
Lots of initial confusion about ME 450	Demonstrates ME 450 core concept
Want to demonstrate design process	Shows multiple stages of a design
Make sure central device is understood	Explains what the device is and what it does
Want more socially impactful ME 450 projects	Appeals to forward-thinkers
Need to keep the information current	Information can be updated as needed

To aid the understanding and analysis of our project requirements, we created 3 subtypes: "Form," "Execution," and "Function." Each subtype had a unique approach to specification research and design. These subtypes may be seen in Table 3.

Table 3. What was referenced to translate requirements into specifications.

Type	Requirements	Research
Form	Passes applicable regulations for commercial air travel	CFR Title 49: Part 175 [31]
	Can fit in a checked bag on commercial flights	Airline Baggage Policy [34]
	The device must present no safety hazards while in operation	"Minimal Force Transmission between Human Thumb and Index Finger Muscles under Passive Conditions" [35]
	Comfortably transported/assembled by one person	OSHA [30] Airline Baggage Policy [34]
	Compatible with range of event tabletops	"How To Maximize the Effect of Your Trade Show Table Covers" [20]
	Can be fabricated within the ME 450 project budget	"Fall 2022 | Financial Processes | Slides" [36]
Execution	Event setup is reasonable	Presenter subjective feedback
	Device must run for duration of daily tradeshow presentation	Presenter objective feedback
	Repair is reasonable	Presenter subjective feedback
	Repair parts or services are easy to find	Presenter subjective feedback
	Information can be updated as needed	Presenter subjective feedback
Function	Draws people into ME booth	"Engaging consumer through the storefront: Evidences from integrating interactive technologies" [14]
	Can keep a person's attention while presenter talks to someone else	"Best Ways to Attract and Hold Online Users' Attention" [37]
	Can draw and keep attention passively	Stakeholder subjective feedback
	Form of backdrop integrated with device	Stakeholder subjective feedback
	Branding aligns with other communications	Department communications guidelines [38]
	Demonstrates ME 450 core concept	"Powerful Marketing Strategy for Consulting Firms to Get Results" [39]
	Shows multiple stages of a design	Faculty subjective feedback
	Explains what the device is and what it does	Presenter subjective feedback
	Appeals to forward-thinkers	"7 Tips to Appeal to the Eco-Conscious Consumer" [40]

The "Form" subtype groups requirements that primarily define physical specifications about the product, like size, dimensions, or materials. We used our prior research in tradeshow standards, commercial flight legislation, and ergonomics theory to establish relevant size, material, and weight specifications.

The “Execution” subtype groups requirements that affect the ease of use and maintenance of the product. It is important to our team that the product is not challenging for the owning party to maintain. When interviewing Eliza, we learned that the display must be designed to be operated and maintained by one person with a busy schedule, limited fabrication resources, and minimal mechanical familiarity. We workshopped these specifications directly with Eliza.

The “Function” subtype groups requirements that affect the primary audience’s interaction with the display. We reviewed our research on design theory regarding average consumer shopping habits and more specific professional articles regarding consulting and targeted-demographic marketing. Although the research did not provide us with physical design specifications which directly affect human behavior, it did define explicit design elements which our solution should implement to achieve the marketing goals of the display.

It is important to consider the importance of each specification to aid concept selection and resource prioritization. Our list of priorities is fundamentally very pragmatic. We see the Form-subtype requirements as most important, as they define legality of the display and feasibility of transportation. Execution-subtype requirements are the next important consideration, because even the best display will not be used if it is broken and unrepairable. Given the importance of the other two subtypes, the Function-subtype is left to lowest priority.

It is critical to note that although our priorities place the functional purpose of the display last, this does not mean we will sacrifice the function of the display in favor of form. Instead, it drives us to ideate concepts that fulfill the lowest-priority specifications while being constrained by the highest-priority specifications. In other words, our highest-priority specifications are effectively addressing Eliza’s needs, while the lower-priority specifications consider her wants.

Following the concept development process (discussed in detail later), we determined that the best way to meet our initial requirements was to separate our display into two components: A central device, serving primarily aesthetic ends, and an informational backdrop, fulfilling the requirements that cannot be met by our central device. Once this design decision was made, additional requirements were added, based on additional interviews with both Eliza and other stakeholders (discussed further in “Stakeholder Analysis” above). Those requirements which were added at this stage are highlighted in gray in Table 4.

Thus, in addition to the above subgroups, we have also divided our requirements based on their applicability to these display components. “Form” and “Execution” requirements mostly apply to the overall display, owing to their more practical focus, while the aesthetic and informational components together must meet the “Function” requirements. We consider the aesthetic requirements to be of higher priority than the informational ones, owing to the complete lack of existing solutions to meet them, whereas the informational requirements are already served to some extent by verbal interaction and existing tabletop flyers.

Pulling together our research and considerations of importance, we were able to outline our complete list of ranked specifications, grouped by the display component they apply to. This information is presented below in Table 4.

Table 4. Requirements and Specifications by Display Component.

Display component	Rank	Requirement	Specification
Overall display	1	Passes applicable regulations for commercial air travel	Does not contain any air-illegal substances
	2	Can fit in a checked bag on commercial flights	Dimensions < 62 linear inches
	3	Comfortably transported/assembled by one person	Individual Lift Weight < 21.8 pounds Total Travel Weight < 50 pounds
	4	Compatible with range of event tabletops	Footprint < 30" x 72"
	5	Event setup needs to be reasonable	< 10 minutes assembly time
	6	Can be fabricated within the ME 450 project budget	≤ $650 material cost
	7	Repair needs to be reasonable	1 person needed < 60 minute repair time
	8	Repair parts or services need to be easy to find	100% of fasteners purchasable off-the-shelf 100% of custom parts can be manufactured at U of M
Aesthetic component	9	Draws people into ME booth	≥ 1 lighting element ≥ 1 brightly-colored element
	10	Can keep a person's attention while presenter talks to someone else	≥ 1 moving element
	11	Can draw and keep attention passively	100% of other aesthetic specifications are met without interaction
	12	Device must run for duration of daily tradeshow presentation	> 8 hour runtime
	13	The device must present no safety hazards while in operation	Tipping Force > 7.21 pounds [35]
Informational Component	14	Form of backdrop integrated with device	All viewing angles align with informational content
	15	Demonstrates ME 450 core concept	≥ 3 previous ME 450 projects for reference ≥ 1 mention of value proposition
	16	Appeals to forward-thinkers	≥ 1 previous socially-conscious ME 450 project for reference
	17	Shows multiple stages of a design	100% of design stages shown for central device
	18	Information can be updated as needed	100% of information is communicated through swappable modes
	19	Branding aligns with other communications	100% of graphical elements meet Department style guidelines
	20	Explains what the device is and what it does	100% of our device's mechanical design innovations introduced

We believe we have developed an adequately rigorous set of specifications which have guided the solution toward something that fulfills the project requirements. When we compare the specifications of our tabletop display to other products with similar use-cases, reassuring similarities become apparent. The Form-subtype specifications intuitively make sense because other air-transported objects like luggage bags must adhere to the same regulations and standards. The Execution-subtype specifications we developed together with Eliza regarding setup and repair remind us of other specialized appliances like a blender, which must be maintained on sparse intervals by a layperson. The aesthetic elements of the Function-subtype specifications reflect elements that we've observed from benchmarked tabletop display solutions in industry, like the minimum of one lighting element, which is a staple across high-end tradeshow and commercial window displays. The informational elements of the Function-subtype specifications are reflective of existing communications from the ME Department.

In order to verify that a solution fulfills its outlined specifications, the specifications themselves must be testable. Every specification we have is either a quantity that may be measured, like size and weight, or a design feature that may be confirmed via inspection, like materials and functional elements. Given this quality of our specifications, we are confident we will be able to test our solution on its specifications, and indeed, we have completed almost all of them and have plans in place to finish this process. Details on our tests may be found in Table 5.

Table 5. Specifications by subgroup and relevant test.

Type	Specification	Test
Form	Does not contain any air-illegal substances Dimensions < 62 linear inches Individual Lift Weight < 21.8 pounds Total Travel Weight < 50 pounds Footprint < 30" x 72" ≤ $650 material cost	● BOM review and inspection verify material legality and budget compliance ● Measurement by inspection tools (tape measures, mass scales)
Execution	< 10 minutes assembly time 1 person needed < 60 minute repair time 100% of fasteners purchasable off-the-shelf 100% of custom parts can be manufactured at U of M 100% of information is communicated through swappable modes	● Time trials verify assembly and repair times ● BOM review and inspection verify fastener sources, custom part fabrication availability, and information modality
Function	≥ 1 lighting element ≥ 1 brightly-colored element ≥ 1 moving element 100% of other aesthetic specifications are met without interaction All viewing angles align with informational content ≥ 1 mention of value proposition ≥ 3 previous ME 450 projects for reference ≥ 1 previous socially-conscious ME 450 project for reference 100% of design stages shown for central device 100% of graphical elements meet Department style guidelines 100% of our device's mechanical design innovations introduced	● Design inspection verifies inclusion of specified design elements and compliance with aesthetic specifications

By developing a set of rigorous specifications, we were equipped with a critical tool in the solution design process. These specifications are the standard on which different potential solutions have been compared. This has ultimately aided concept selection and refinement.

CONCEPT GENERATION

With the idea of a tabletop display, the possibilities are endless when it comes to the final product. To be sure we were thinking of the best possible solutions, we utilized divergent thinking, the 4 P's of Creativity, and a few additional practices. These methods allowed us to generate over 100 concepts that could be used to create the ultimate alpha design.

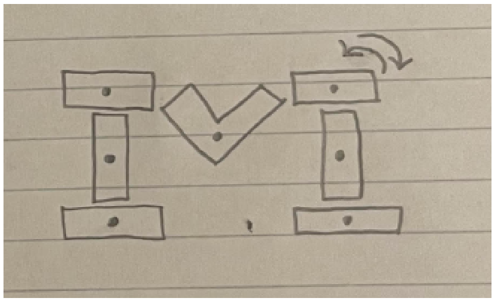
Beginning with divergent thinking, our group benefited a lot by asking ourselves open-ended questions. When there is not a strict solution to a particular question, there is room for creativity to take over as you think about the different ways to answer it. A big question that inspired a lot of our concepts was, "How can interaction be implemented?" and the reason it worked so well for us is because it allowed us to not only think of the different types of interactions but also how you make different parts of a single concept interactive, which leads to more concepts.

To be sure we stayed centered on our problem at hand, we utilized the 4 P's of Creativity, which stand for person, process, product, and press. The role of the person category is to consider the perspectives that we bring as the creators of these concepts. Since a part of our goal is trying to represent the students of the University of Michigan, we had to be mindful of our bias so we did not skew too hard on that idea with the consequence of not adequately representing the broader University community. Process addresses the number of concepts that we wanted to create; we aimed for a minimum of 100 and finished with 160. Creating this many designs gave us a multitude of features to choose from to form the alpha design later. Product is where we are mindful of how the concept fits into the requirements and how it considers the different stakeholders. This category is arguably the most important because it is the one that anchored our minds to our project and what we are trying to accomplish. It is what separated the ideas of something like a simple vase from a rotating linkage system that forms an "M." We found ourselves referencing our requirements a lot to be sure we were on the right track as well as coming up with new ideas based on which stakeholder we focused on. Lastly, press considers the environment we were in while ideating. We started off ideating individually and then later moved to a collaborative space to come up with our remaining concepts. We made sure to free ourselves of any distractions as well to be sure we maintained clear, level heads. [41]

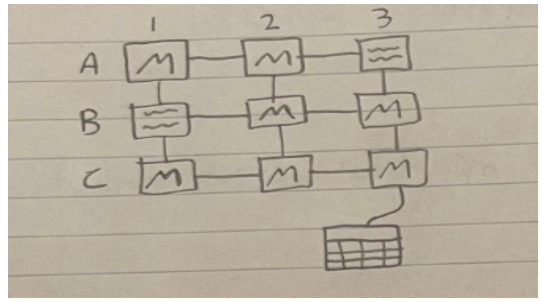
In addition to the two methods mentioned above, there were also other practices that were used to help generate ideas, especially in group meetings. Sketching was a common practice that we found ourselves doing to better communicate our abstract ideas. Encouraging wild ideas inspired others to think of simpler ways to achieve similar results. This went along well with deferring judgment because you never know what idea might inspire another that could potentially be the final choice. The flip side to this is building on others' ideas because it allows for even better ones to be born. Finally, one practice that we originally did not think was going to be involved as much was having one conversation at a time. It is really easy to be inspired by someone in the midst of them talking and then to try to say your idea out loud before you forget. We found this to be counterproductive, so we decided to write down our ideas whenever someone else was speaking and waited for them to explain their idea. [42]

After establishing our 160 concepts, there were 7 main concepts that we chose to focus on (through methods described later in this report); sketches can be seen in Table 6.

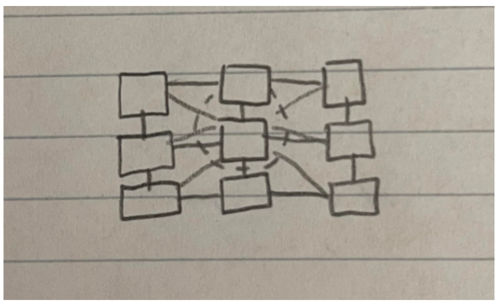
Table 6. Sketches of 7 main concepts we selected to focus on: (a) kinematic sculpture, (b) memory game, (c) exploded Rubik's cube, (d) Rube Goldberg device, (e) perspective clock, (f) kinematic mirror, (g) business card stamping machine.



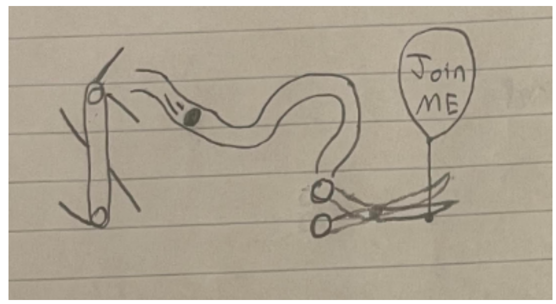
(a)



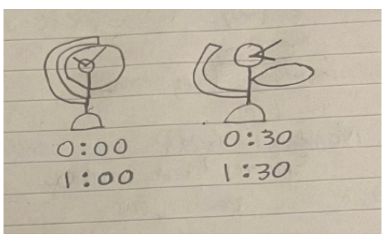
(b)



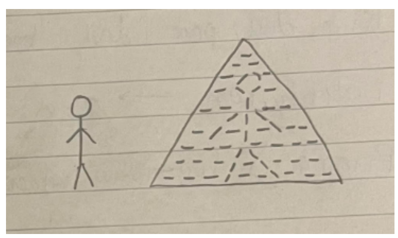
(c)



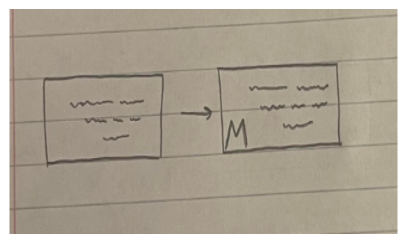
(d)



(e)



(f)



(g)

The kinematic sculpture began as a group of links that can form various shapes through their combined motion, such as the University of Michigan's signature "M" logo. These links could also have buttons on them that allowed the viewer to rotate them individually. By adding this element, it adds a puzzle-like aspect, giving viewers the opportunity to try to determine the shape the links would form to make.

The memory game allows the viewer to learn information about the sponsorship program that would otherwise be on a separate informational display. The viewer would enter two inputs for their selection and the cards would automatically flip over revealing the other side, switching back if incorrect and remaining otherwise.

The exploded Rubik's cube was an idea derived from the giant Rubik's cube found in GG Brown and is a working Rubik's cube that has its colored blocks extended from the center body to expose the mechanism that allows the toy to work.

Our primary idea for a Rube Goldberg device was a series of ME-related contraptions that would transport a ball, loaded by the viewer, from a starting position to its destination, releasing a balloon that reads "Join ME," though other concepts would also have been possible.

One common thing people need to know at tradeshows is the time, which inspired the perspective clock. The idea behind this concept is that we would make a sculpture of a clock face that would either change its shape revealing a different sculpture every few seconds, or the sculpture would force the viewer to stand in a certain position to read the time.

Arguably the most visually pleasing idea is the kinematic mirror, which would use sensors and motors to position different pieces of metal to create a "mirror" image of whatever is standing in front of it.

Last is the business card stamping machine. Since the design will be at a tradeshow, there will be plenty of business professionals who will potentially have business cards, and we could stamp the Michigan "M" logo on to them to provide a keepsake without consuming additional materials. We could also keep a stack of business cards with important information to allow those who do not have business cards to use the stamping machine. These 7 concepts were the main ideas we decided to move forward with, but the remaining concepts may be found in Appendix A.

CONCEPT SELECTION

The general concept selection process we followed was screening to evaluation to selection. This process was not necessarily linear, as there was some back and forth between the separate stages, but in general, that was the overall flow. Screening was used to organize our solution space, where we used techniques such as clustering, removing duplicates, and applying screening criteria [43]. Evaluation was used to narrow down our solution space. Here we answered the question, "Which solutions best address the design needs?" We could relate this to some of our stakeholder requirements, such as, "Is the design attention-grabbing/keeping?" and, "Is the design mechanical engineering focused?" For the selection phase, we reflected on the advantages and limitations of each concept. Here we used Pugh matrices [44, 45], where we conducted three stages: unweighted, weighed, and weighted granular.

As previously mentioned, our general process led from screening to evaluation to selection. This allowed us to close in from divergent to convergent concepts. Our progression from 160 unorganized concepts to our top 7 organized concepts is visualized in Figure 11. These top 7 concepts were from our first round of concept generation. Our entire concept selection process is detailed in Appendix B.

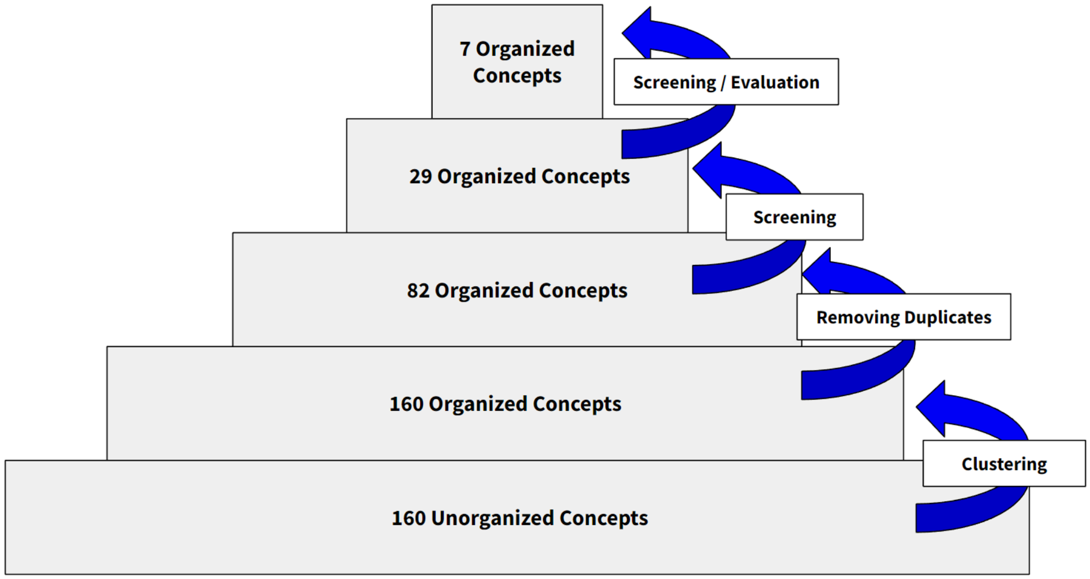


Figure 11. Concept generation & selection. Note the different concept selection techniques used for this process, from 160 unorganized → 160 organized via clustering, 160 → 82 via removing duplicates, 82 → 29 via screening, and finally 29 → 7 via screening/evaluation. This visual is imperfect, as it depicts the stages as linear, when in actuality they were more iterative, but it demonstrates the progression of the convergent stage of our concept development process.

Breaking down our selection methodology, we began by clustering similar ideas together. The clusters we came up with were: mirrors, kinematic sculptures, puzzles, Rube Goldberg devices, games, art, engineering demonstrations, automated robots, souvenir factories, and clocks.

Our screening and evaluation criteria consisted of packaging feasibility, no-go's, evaluating if designs were ME-focused, design feasibility, liability concerns, and gut checks. Our no-go's were any designs we considered dangerous, produced annoying noises, or contained illegal substances. Our gut check [46] considered if we believed the designs to be "wow-inducing."

Our first round of concept selection culminated in using the Pugh matrix technique for selection. Our Pugh matrix criteria were derived from our stakeholder requirements. Three rounds of Pugh matrices were conducted in order to further justify our selection. In order to understand our Pugh matrices, it is important to first define each of our criteria.

"Assembly complexity" is defined as how hard the tabletop display is to set up at tradeshows. Designs that have more pieces or require highly precise setups scored worse than designs that have fewer pieces or are easily modular.

"Can gain attention" is defined as the ability of the display to initially catch viewers' attention as they are walking by. Designs that are larger, have moving elements, or are particularly unique scored higher.

“Can hold attention” is defined as the ability of the display to hold viewers’ attention once they are near the table. Designs that facilitate physical interaction, have visually interactive capabilities, or showcase interesting mechanical designs scored higher.

“Embodies ME 450 core concepts” is defined as having the ability to showcase core ME principles, the design process, or anything relating to the structure of the course. Designs that are able to embody these scored higher, and designs that explicitly show these principles even moreso.

“Serviceability” is defined as the ability for the display to be repaired. We defined repair as larger-scale work that would not be able to be done by the presenter at the tradeshow. Designs that have many custom-made components, complicated designs, or a high number of components scored worse.

“Design complexity” is defined as the level of intricacy in the design. Highly complicated mechanisms would pose additional challenges in completing them within the scope of this semester. Designs that are very complex and that we could not easily benchmark or research scored lower.

We began with an unweighted Pugh matrix, where the top 7 concepts were compared to one another using the criteria stated previously. This is shown in Table 7.

After this, we completed another Pugh matrix, this time weighting the criteria based on project importance. “Can gain attention” and “Can keep attention” were weighted the highest at 10, since we feel those are the two most important aspects of our design. Next, “Design complexity” was weighted as an 8, since we aim to have a design that works very well by the end of the semester. “Embodies ME 450 core concepts” was weighted as a 7, since it is an important stakeholder requirement that the project can convey this in order to drive in more sponsors for ME 450. “Assembly complexity” was weighted as a 5, because while it is important that the presenter’s daily setup not be too difficult, the overall success in attracting sponsors is not directly affected by this criterion. Last, “Serviceability” is weighted as a 3, since skilled personnel will be available if necessary to conduct large repairs, and we intended to design the device such that the presenter does not encounter catastrophic failures when such services are not readily available, such as when “on the road” at tradeshows. Our weighted Pugh matrix is shown in Table 8.

Finally, we completed one more matrix. This time we used the weighted criteria and added granularity to the scoring, with values ranging from -2 to +2. This enabled finer tuning in the scoring. Our weighted granular Pugh matrix is shown in Table 9.

Table 7. Unweighted Pugh matrix. The criteria were not weighted relative to one another. Scoring was from -1 to 1. This resulted in the Kinematic Sculpture winning, as is highlighted in blue.

Criteria	Weight	Kinematic Sculpture	Memory Game	Exploded Rubik's Cube	Rube Goldberg Device	Forced Perspective Clock	Kinematic Mirror	Business Card Stamping Machine
Assembly complexity	1	0	1	1	-1	0	-1	1
Can gain attention	1	1	-1	0	1	1	1	-1
Can hold attention	1	1	1	0	1	0	1	0
Embodies ME 450 core concepts	1	1	1	0	-1	-1	0	1
Serviceability	1	0	0	-1	-1	0	-1	0
Design complexity	1	0	0	-1	-1	0	-1	0
Total Score		**3**	**2**	**-1**	**-2**	**0**	**-1**	**1**

Table 8. Weighted Pugh matrix. The criteria were weighted relative to one another. Most notably, "Can gain attention" and "Can hold attention" were weighted the highest. Scoring was from -1 to 1. This resulted in the Kinematic Sculpture winning, as is highlighted in blue.

Criteria	Weight	Kinematic Sculpture	Memory Game	Exploded Rubik's Cube	Rube Goldberg Device	Forced Perspective Clock	Kinematic Mirror	Business Card Stamping Machine
Assembly complexity	5	0	1	1	-1	0	-1	1
Can gain attention	10	1	-1	0	1	1	1	-1
Can hold attention	10	1	1	0	1	0	1	0
Embodies ME 450 core concepts	7	1	1	0	-1	-1	0	1
Serviceability	3	0	0	-1	-1	0	-1	0
Design complexity	8	0	0	-1	-1	0	-1	0
Total Score		**27**	**12**	**-6**	**-3**	**3**	**4**	**2**

Table 9. Weighted granular Pugh matrix. The criteria were weighted relative to one another. Scoring was from -2 to 2. This resulted in the Kinematic Sculpture winning, as is highlighted in blue.

Criteria	Weight	Kinematic Sculpture	Memory Game	Exploded Rubik's Cube	Rube Goldberg Device	Forced Perspective Clock	Kinematic Mirror	Business Card Stamping Machine
Assembly complexity	**5**	0	2	2	-2	0	-1	2
Can gain attention	**10**	1	-2	0	1	1	2	-1
Can hold attention	**10**	1	1	0	1	0	2	-1
Embodies ME 450 core concepts	**7**	0	2	1	-1	-1	0	1
Serviceability	**3**	0	1	-1	-2	0	-1	-1
Design complexity	**8**	0	0	-1	-2	0	-2	-1
Total Score		**20**	**17**	**6**	**-19**	**3**	**16**	**-14**

Looking at the Pugh matrix results, the "Kinematic Sculpture" design won in each of the three rounds. It is important to note that this was not a preconceived notion that this design would win. Our team actually expected either the "Exploded Rubik's Cube" or the "Forced Perspective Clock" to win, since those were the first solution concepts our team had been informally ideating on since our project was assigned. There is slight evidence of fixation, since each of those designs made it to this stage, but neither design won. Additionally, we did not expect the "Memory Game" to score as highly as it did, but its ability to directly communicate ME 450 core concepts, ability to hold attention, and assembly complexity allowed it to rise to second place consistently.

Importantly, we did not blindly trust the Pugh matrix results. Although we were confident in our criteria and weightings, we held further conversations regarding the results to determine if this was the concept we wanted to move forward with. We determined that the "Kinematic Sculpture" was a great concept that objectively satisfied all of the stakeholder requirements and engineering specifications pertaining to the central display. From here, we moved on to another phase of concept development we call "concept refinement," where we developed and refined more "Kinematic Sculpture" ideas and then selected the best one as our alpha design.

CONCEPT REFINEMENT

After selecting kinematic sculpture, we had to develop the best idea from this concept. We continued to utilize divergent thinking, the 4 P's of Creativity, and the other practices outlined in Concept Generation, and we also incorporated convergent thinking, functional decomposition, and design heuristics.

Once we were more focused on creating an alpha design to address our problem, we had to start converging our thought processes. We had to start thinking about ideas that we could feasibly achieve with methods we have available to us. This would enable us to bring concepts into reality as something we could design and manufacture within the semester. Another aspect we wanted to consider was how our main device would be integrated with the informational backdrop to ensure synergy between the aesthetic and informational components of our display.

When trying to develop these refined concepts, some problems arose that stunted our process. We sometimes found ourselves facing obstacles, which mostly came in the form of mental blocks. These mental blocks were limits we were putting on ourselves like thinking we did not have enough time or that our budget was too low to achieve what we wanted to. Another problem was holes in ideation, meaning running out of steam and believing we had enough ideas [47]. To overcome these problems, we used the techniques of functional decomposition and design heuristics. Breaking down concepts with functional decomposition and changing aspects of our concepts using design heuristics, we were able to surpass those obstacles and holes to create new ideas that seem feasible within our project limits [48, 49].

Our concept refinement phase resulted in more-focused solution concepts. With these, we were able to get a more comprehensive look at our designs. We looked at specific executions of the concepts, contemplated how they worked, and used mechanical engineering principles to analyze things like the number of motors needed, wiring complications, controls, programming, and what materials we could use so that we could get a good sense of if these were ideas that we wanted to explore further. We used our previous experience from ME 250 and 350, internships, and other project teams to inform these decisions. We also did some additional benchmarking to see if some designs were feasible.

We utilized stakeholder engagement to answer the question, “Is this what the audience wants?” We met with Eliza, our project sponsor and the anticipated tradeshow presenter. During this meeting with her, we confirmed which designs would be interesting to viewers based on her experience at these tradeshows. Additionally, we confirmed evaluation criteria for the selection of a refined concept. Again, these criteria were derived from our stakeholder requirements. This meeting allowed us to confirm that our two frontrunner ideas, the “Block M Links” and the “Forced Perspective M,” would be interesting to the audience.

Our second phase of concept selection utilized a new selection technique. For this phase, we opted for a pro-con list as opposed to a Pugh matrix. We did this so that we would not be constrained by the Pugh matrix categories. With this method, we could more holistically evaluate the strengths and weaknesses of each design. Our top five designs are detailed below.

“Block M Links” has the Michigan Block M separated into different rotating links. These links would be individually controlled by their own motors and rotate about themselves. A control box would be implemented for each of the linkages to allow for user interactivity to “complete the puzzle.”

“Forced Perspective M” separates Michigan’s Block M into two halves which counter-rotate about a shared axis to create a negative image of the “M.” This design would allow us to showcase the mechanical design of the gearbox as well.

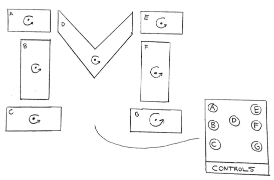
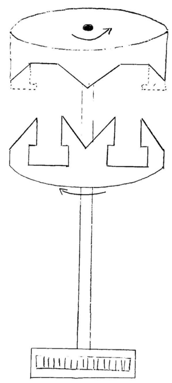
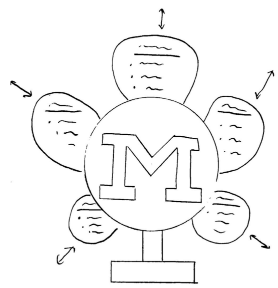
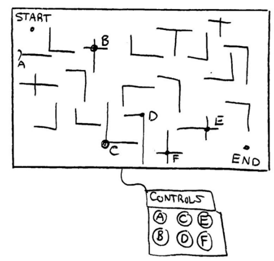
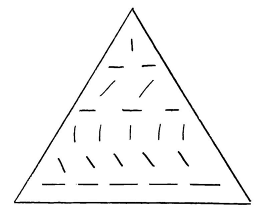
“Flowering Information” allows different pieces of information to expand outwards from the center of the sculpture and contract back behind it. Each of the petals would contain a different piece of information.

“Kinematic Maze” allows the user to interact with the display to complete the maze from start to finish. The control box would link to different components of the maze. The goal would be to complete the maze, but without moving the pieces, a solution from start to finish would not be possible.

“Abstract Art” involves many moving linkages to make different images on the display. There could be a control box implementation that allows the user to pick which arrangement they see. This design would require many motors to rotate each of the individual linkages.

A direct comparison of the designs is depicted in Table 10. The full pro-con list [50] for each of the final designs is depicted in Appendix C.

Table 10. Final five designs comparison. The sketches of each of the designs are shown along with highlights of the advantages and disadvantages of each design. This selection process resulted in the "Forced Perspective M" winning, highlighted in blue.

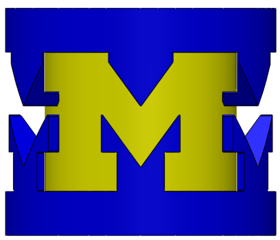
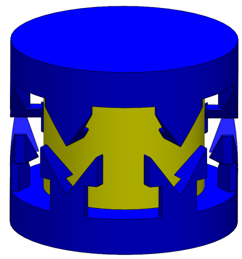
Option 1: Block M Links	Option 2: Forced Perspective M	Option 3: Flowering Information	Option 4: Kinematic Maze	Option 5: Abstract Art
				
• Interactive • Can be integrated with info • Interchangeable parts • Easier to fabricate • More-manageable failure modes • Stable	• Eye-catching • Elegant & mesmerizing • Fewer parts, for easier assembly • Viewable from wide angles • Constant motion • No complicated controls • Simple wiring • Cool lighting integration	• Can be integrated with info • Accessibility challenges with moving text • Needs to be large • Difficult to fabricate • Difficult packaging geometry • ME focused • Difficult to service • Not physically interactive	• Interactive • Moving parts • Difficult controls • Difficult to service • Needs to be large • Difficult to make work • Cool to play with	• Many moving parts • Difficult to make work • Requires many motors • Difficult controls • Difficult wiring • Difficult to service • Unique art designs • Generic

Unlike the Pugh matrix results, there was not a design that earned a top score. Instead, we compared the advantages and disadvantages of each of the designs holistically. We discussed which of the designs best fit our project needs, stakeholder requirements, and engineering specifications. In particular, we discussed which of the designs would have the biggest "wow-factor" when passing by the table, as well as when you got a closer look at the display. With all of this in mind, our team decided that the best design to move forward with was the "Forced Perspective M."

CONCEPT DESCRIPTION

Our team chose to create a kinematic sculpture to attract a mechanically-minded, diverse audience to the table of an ME 450 presenter. To minimize the barrier to entry for observing and appreciating the kinematic sculpture, we chose to avoid concepts using heavy-handed information presentation or physical control systems. We challenged ourselves to achieve a display that is capable of speaking for itself. We believe the "Forced Perspective M" concept is the best solution to our problem statement, and we developed the concept into an alpha design we have named "The Beacon," which may be seen in Table 11.

Table 11. Two CAD images of The Beacon shown in comparison with one image of the Block M logo.

		
The Beacon Front View	**The Beacon** Iso View	**University of Michigan** **Block M [51]**

The Beacon is a forced perspective kinematic sculpture which fundamentally represents the University of Michigan by reimagining one of the most recognizable single-letter icons in the world: the Block M. Composed of two rotary halves joined by a maize-tinted, illuminated internal surface, a negative image of the Block M is revealed when observing The Beacon from any of 6 different angles around the assembly. Preliminary scale of The Beacon may be seen in Figure 12.

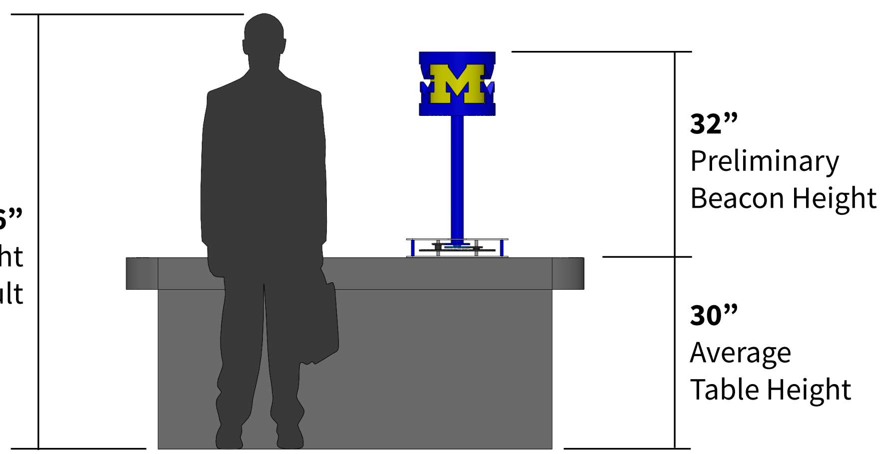
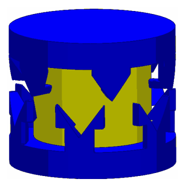
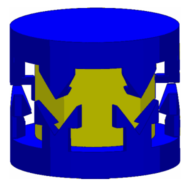
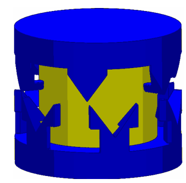
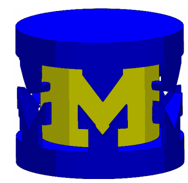


Figure 12. Front view diagram demonstrating the scale of The Beacon compared to a person

By implementing a subtle kinematic motion into The Beacon, the display entices distant viewers to come closer and explore how mechanical engineering enables such motion. We have designed The Beacon to periodically pivot the upper and lower halves in opposite directions, deconstructing the Block M. After drifting for a few moments, the halves continue to pivot back into alignment, reconstructing the Block M. It rests for a few moments before repeating the cycle indefinitely. This progressive motion may be seen in Table 12.

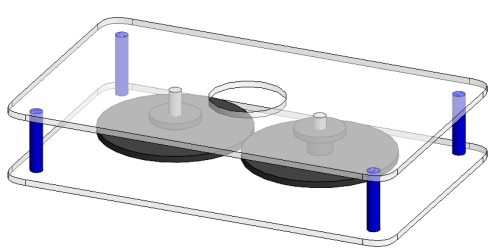
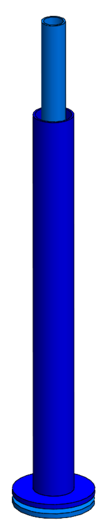
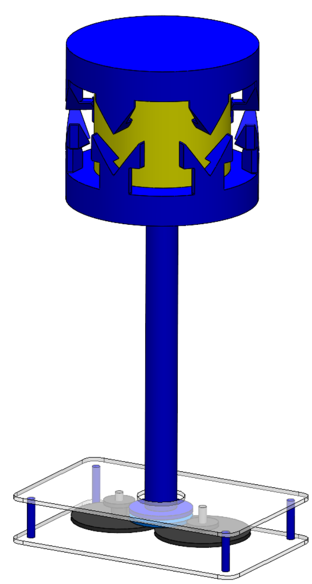
Table 12. Progressive images demonstrating the motion of the two Beacon halves

				
Step 1	**Step 2**	**Step 3**	**Step 4**	**Step 5**

To improve the visibility of The Beacon and speak to the engineering capabilities of University of Michigan mechanical engineering students, we have developed two other systems: a gearbox baseplate and a coaxial support. These systems and their final integration together may be seen in Table 13.

The coaxial support assembly would elevate The Beacon to better draw attention and facilitate the perspective effect, maintaining a slim silhouette at the same time. The gearbox baseplate assembly houses all the related mechanical and electrical components which drive the rotary function of The Beacon. Separating the device into three sub-assemblies enabled our team to explore a wider solution space for transporting the display in a deconstructed state.

Table 13. Preliminary CAD models demonstrating the integration intent of three subsystems

		
Gearbox Baseplate Iso View	**Coaxial Support** Iso View	**Integrated Assembly** Iso View

Another critical specification of our system is the need for “≥ 1 lighting element.” Taking inspiration from the fact that the state of Michigan contains the greatest number of lighthouses in the United States [52], we chose to challenge ourselves to integrate a lighting solution directly into the center of The Beacon, similar to the guiding light of a lighthouse. This challenge required some specialized knowledge in the field of lighting engineering, but we overcame that by referencing existing lighting solutions like lamps and by utilizing core electrical wiring skills. A render demonstrating the internal lighting solution may be seen in Figure 13.

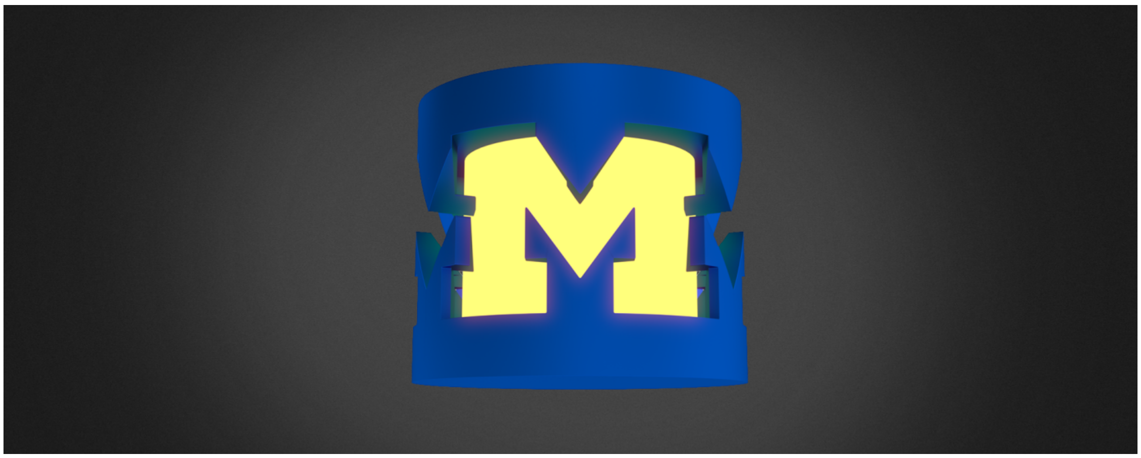
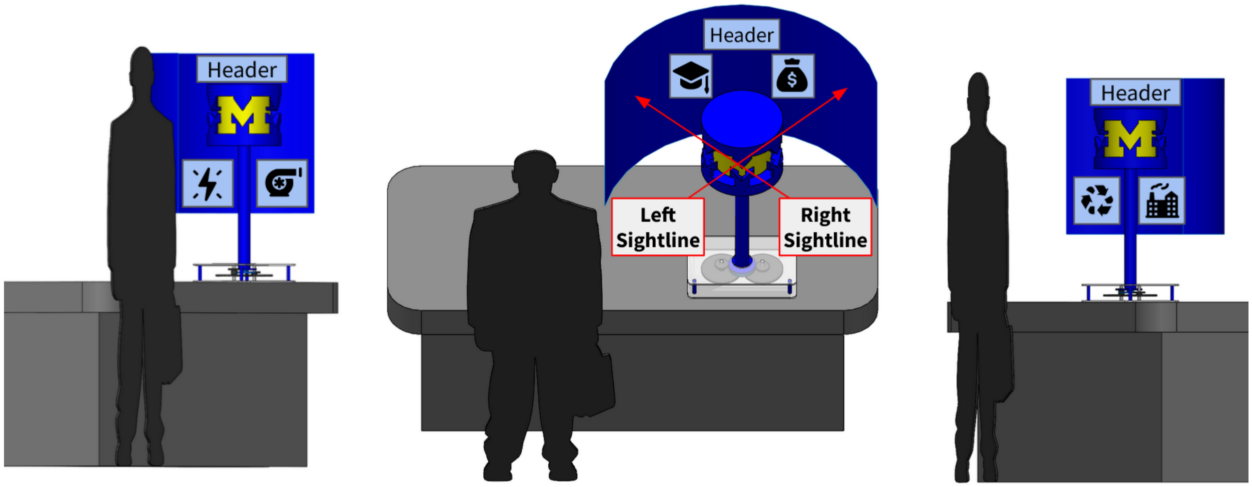


Figure 13. Lighting-accurate render of The Beacon highlighting the internal illumination. Note the light yellow glow bouncing off the internal surfaces of the sculpture.

The Beacon is accompanied by an informational backdrop to present to viewers details about the ME 450 course, its value proposition to companies, and what kinds of projects have previously been done. Our team has aimed to use the alternative forced perspective angles of The Beacon to drive a viewer’s gaze around the different sections of information on the backdrop. By integrating The Beacon as a design element together with the blocks of information on this backdrop, we avoided a need to overtly stamp the backdrop with University of Michigan branding, given that The Beacon itself establishes the ethos of the University to an external observer. Table 14 demonstrates how different viewing angles enable us to guide attention around the informational backdrop. We are utilizing swappable panels to enable replaceability of information.

Table 14. Three diagrams demonstrating how the forced perspective aspect of the kinematic sculpture directs viewer attention in different directions around the informational backdrop.



View from left angle	Elevated view from center angle	View from right angle

ENGINEERING ANALYSIS

Gearbox Geneva Mechanism

The primary mechanical function of The Beacon, its intermittent rotary motion demonstrated in Table 12, fulfills one of the most important specifications: "≥ 1 moving element". To enable this function, our team designed a custom Geneva mechanism gearbox in the baseplate subsystem. The Geneva mechanism produces intermittent motion by using a wheel with a pin to drive another wheel with a mating slot for the pin, as shown in Figure 14. In our system, the drive wheel is powered by a motor, and the driven wheel is directly connected to one half of The Beacon. A mirrored set of wheels, rotating in the opposite direction, drive the opposite half of The Beacon off the same motor. This ensures The Beacon's halves remain mechanically interlocked and indexed without a need to angularly align the halves manually.

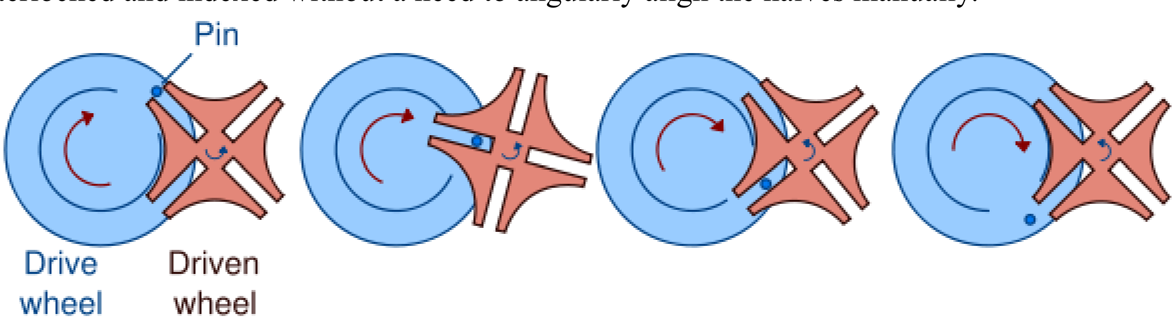
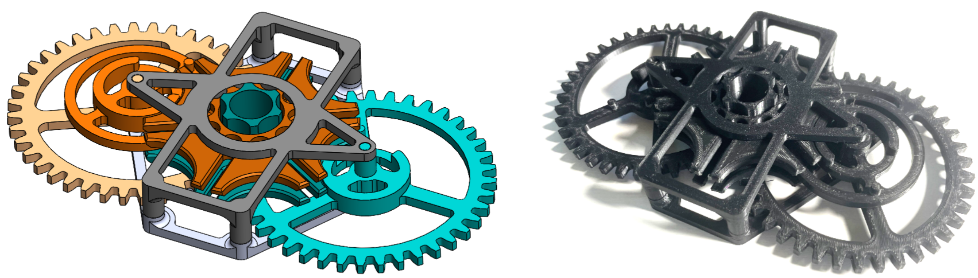


Figure 14. Progressive diagram demonstrating the function of a Geneva mechanism [53].

To verify that our Geneva wheel and coaxial shaft system work correctly, we planned a Prototype I phase. During this phase, we dedicated our time on completing the CAD model of the gearbox assembly and 3D printing this mechanism to verify it works correctly in real life. The CAD model is shown in Figure 15a, with the 3D printed model shown in Figure 15b.



(a) (b)

Figure 15. (a) CAD model of Prototype I of our Geneva wheel and gearbox mechanism. (b) 3D printed model of our Geneva wheel and gearbox mechanism.

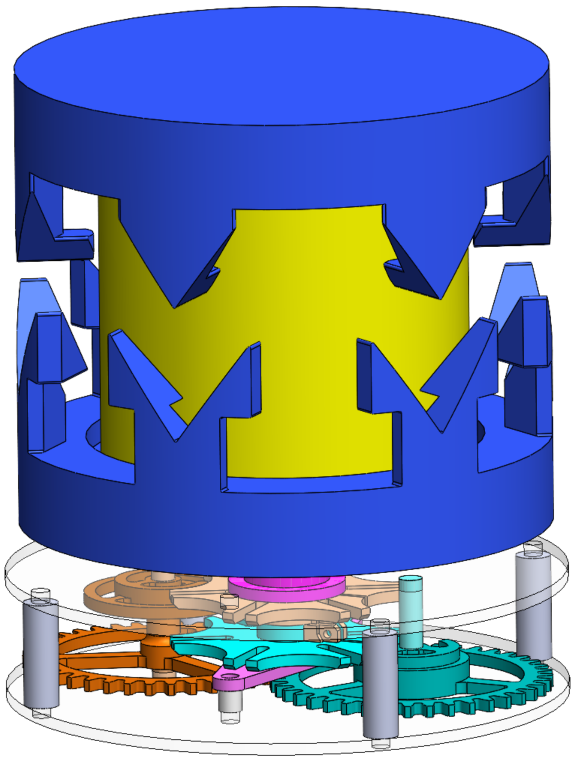
The questions we wanted to answer were: “Can we design a functional mechanism?”, “Is 3D printing a viable method of fabrication?”, and “Are the aesthetics interesting?” By inspecting our Prototype I, we chose to answer “yes” for all of the questions above. The prototype mechanism had fairly high friction and squeaked during motion, but successfully indexed the two geneva wheels as planned. We learned that 3D printing was a viable method of fabrication as the material was geometrically sound, rather strong, and had a decent surface finish. After presenting the prototype in the class, we found that the mechanism sparked curiosity in others due to the general unfamiliarity with the Geneva concept and handwatch-like aesthetics of the component lightweighting geometry, proving it was interesting to view.

Half-Scale Prototype - Build Design

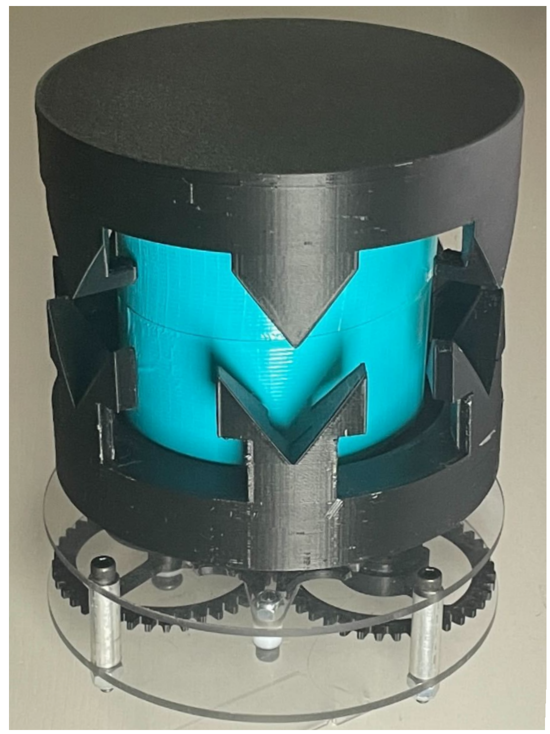
The engineering and testing of our Build Design was provided about one week in our semester timeline. The critical decision when conceptualizing our Build Design was determining which details of our Final Design concept must be verified soonest. Considering the background experience of our members, we decided it was most important to verify the functionality, manufacturability, and durability of a co-axial Geneva mechanism which structurally supports The Beacon. Omitting details of our concept, like the integrated lighting solution, when engineering the Build Design enabled us to design and test the remaining details of our design concept much faster, informing us sooner on whether or not the overall concept would fulfill our technical requirements.

The team chose to create a 50% dimensional scale model as our Build Design to observe in real life how the forced perspective of The Beacon functions, if the chosen construction methods are adequate for the Final Design, and if the display as a whole remains aesthetically interesting. The Build Design aligns with the Final Design on mechanism component proportions, packing/assembly process, some material selection, overall aesthetics, and viewing angles. The two designs differ in that the Build Design lacks lighting, some nuances in the mechanical design are different, it is hand cranked, and the entire display is half the size.

To create the Build Design, the Prototype I model was scaled appropriately and modified to structurally support a 50% scale Beacon. Sections of the mechanism were redesigned to a plate-and-standoff style construction, which was convenient for our manufacturing capabilities. The CAD model and final physical embodiment of the Build Design may be seen in Figure 16.



(a)



(b)

Figure 16: (a) CAD model of Build Design. (b) Physical prototype of Build Design

The timeline of the Build Design was one of the critical drivers for many engineering decisions on the Build Design. Our team chose to take advantage of an accessible 3D printer and CNC router to quickly manufacture mechanical and structural components from PETG filament and polycarbonate sheets. On-hand bolts were utilized as makeshift axles, and off-the-shelf nylon spacers provided rigid support between the baseplates. A summary of the materials and components which comprised the Build Design may be found in Appendix D.

Using the Build Design, our team manually rotated the mechanism to intuitively gauge its design success. We found that the proportions of the design enable a rigid assembly that adequately supports kinematic components such that there is little backlash in the gears, there was smooth rotary action with no jamming, and the mechanism operating as expected. The 50% model gave us confidence that when the design was scaled up to 100%, the mechanism and supporting mechanical components would be able to fulfill their associated functional specifications.

Packaging Analysis

A large constraint to our design is its need for everything to fit into checked luggage. The specification for this is for the packed dimensions to be less than 62 linear inches. In order to visualize this in CAD, we benchmarked a suitcase with outer dimensions 31”x17”x14” and inner “packing” dimensions 29”x16”x14” [54]. Importantly, we benchmarked a hardshell suitcase so that it is durable while remaining lightweight [55]. Our packaging analysis with all of the main components is shown in Figure 17.

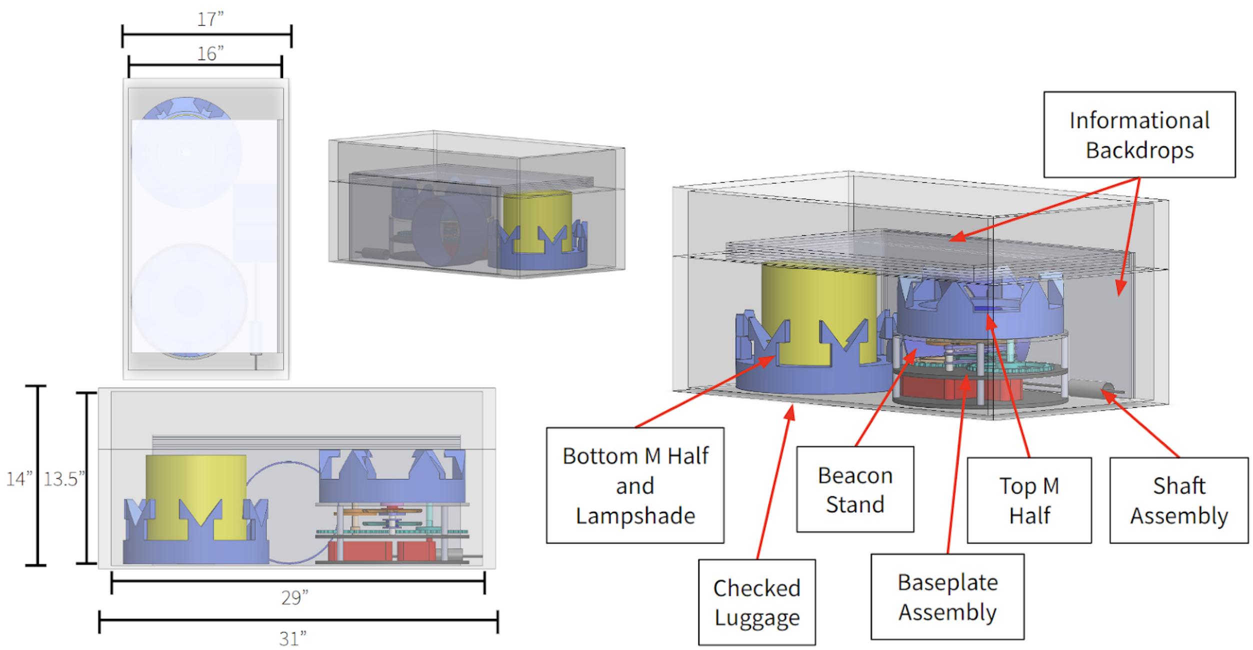
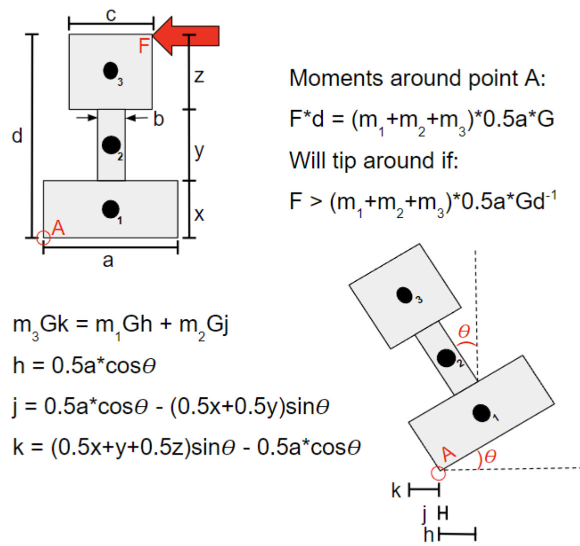


Figure 17. CAD packaging analysis of The Beacon and informational display. Note the highlighted assemblies and components are laid out in the CAD: the bottom M half and lampshade, shaft assembly, baseplate assembly, top M half, beacon stand, and informational backdrops. We intend to also support the components using foam to secure them in place and prevent damage while traveling.

Our packaging analysis drove design changes like shrinking the baseplate footprint, slightly decreasing the overall dimensions of The Beacon, and influencing the decision to raise the whole assembly up on a polycarbonate stand rather than having a very long coaxial shaft system. This design change will be discussed in more detail in the Final Design Description section.

Tipping Analysis

To be sure that our central device does not fall over, we did some theoretical testing with free body diagrams involving a tipping force. This tipping force represents the required force needed to cause our central device to tip over one of its edges, which was found to be approximately 8 lbs. We also calculated the angle the central device needs to rotate before it falls over. Both of these calculations can be seen in Figure 18. After conducting research, we found that an average force exerted by people between the ages of 33 and 55 is 7.21 lbs [35]. We compared this force to the tipping force, and since the force needed to tip the device is more than the average force that people exert when they “poke,” we believe our central device will be safe from the casual actions of human curiosity. Additionally, we are also considering strapping down our central device to the table to further stabilize the device. Empirical testing could be helpful now that the final design is brought to life to be sure that the device will not fall over.



	Gearbox	Shaft	Beacon	
	m_1	m_2	m_3	Total
Mass (lb)	9	1	4	14
	a	b	c	G: gravity
Width (ft)	2	0.0833	0.8333	32.2 ft/s
	x	y	z	d
Height (ft)	0.8333	1.3333	1.4742	1.75
Force F (lb): 8.00			Angle *θ* (deg): 73	

Figure 18. Free body diagram analysis to calculate the force required to tip our central device and the angle the device must overcome before it falls over.

Material Selection Analysis

Looking forward to the final design, our team knew we would have to make quick decisions for material selection on many parts like mechanical components, aesthetic components, and structural components. In our semester-long timeline, rapid fabrication and process accessibility were critical constraints. Considering this, the rationale for each of the components could be justified.

Mechanical components like baseplates, Geneva wheels, gears, and mounting supports were chosen to be constructed from acrylic due to its glossy finish, scratch resistance, low-friction, lightweightness, and laser cuttability [56, 57].

The Beacon aesthetic "maize lamp shade" is inherently a large, hollow tube shape. Cut tube stock was chosen to construct this as we could source off-the-shelf, diametrically correct stock in various materials. Polycarbonate was the material of choice since we were more confident in safely cutting the polycarbonate tube to size on a band saw than a fragile, thin acrylic tube [58]. Thin films could be sourced off-the-shelf and adhesively applied to diffuse internal light and provide yellow tinting.

Structural baseplate spacers and gear axles were chosen to be turned from aluminum on a lathe as they would be cheap, quickly manufacturable, and strong [59].

The final design would need two coaxial shafts. The inner coaxial shaft was chosen to be an off-the-shelf hardened carbon steel as it is smooth, hard, wear resistant, and torsionally-stiff [60]. The outer coaxial shaft was chosen to be carbon fiber tube since it is aesthetically impressive, lightweight, has high torsional stiffness, and can be easily cut on a bandsaw [61].

Bearings were chosen to be made out of POM plastic due to its high dimensional stability, strength, toughness, and rigidity, as well as its outstanding wear resistance and excellent machinability [62].

The top and bottom halves of The Beacon, fittings, cams, and lighting structure were chosen to be made out of PETG as it is strong, durable, and can be sourced as filament for accessible FDM 3D printers, which we believe is the best manufacturing option for these components due to the short turnaround time needed [63, 64].

All of the named components can be seen in the labeled final design figure in Appendix E.

Informational Backdrop Analysis

One of our main conceptual details was the integration between the central device and the informational backdrop. Our display design accomplishes this by aligning each viewing angle of The Beacon with content on the backdrop, drawing viewers' eyes to it and encouraging exploratory viewing of the backdrop from different angles.

Because the intended perspective effect is highly sensitive to viewing distance, we decided to longitudinally separate the backdrop from The Beacon as much as possible, reducing parallax and allowing for a wider range of viewing distances. As a result of this decision, coupled with the fairly large size of The Beacon, we needed the backdrop to be as wide as possible to allow visual space on either side of The Beacon in which to place content. To meet this need for all three viewing angles, we found the complete backdrop needs to be much wider than a 62-linear-inch suitcase allows. In order to make it fit, we composed the backdrop of several separate panels, which can be taken apart and stacked flat in a suitcase. With three discrete Beacon viewing angles, we needed information on three vertical panels. We have, in essence, derived the tri-fold display from first principles.

Typical pre-made tri-folds do not fit in standard suitcases [29]. This presented both a problem and an opportunity. We had to create our own display, which meant more work in a short timeline, but also the ability to make it whatever size and shape we want. Working within the size constraints of standard tradeshow tables and plane-compliant suitcases, we needed to create a display that was integrated in form with the central device while also not being blocked by it.

We had initially planned for The Beacon to be mounted at eyeline (32 inches above the table to its centerline [20, 21]), so to ensure the informational backdrop is visible above it while accounting for variations in height and viewing position, we had intended to make it 61 inches tall. To fit in a 62-linear-inch suitcase, each panel was to be 27 inches wide and divided into several segments with heights under either 10 inches or 17 inches, allowing all panels to be stowed on either the top or the long sides of the interior space.

However, upon mocking up that 61-inch height with a tape measure, we discovered that it was overbearingly large, and we decided to reduce this height to 45 inches, which was relatively easy because the bottom segments already did not have any content on them in order to avoid it being blocked by the central device. To maintain proportions and provide more margin in packaging, this change was accompanied by a reduction in width, with each panel now being 24 inches wide. In order to maintain alignment between the backdrop and The Beacon, we lowered the latter's centerline to 16 inches above the table, which had the added benefits of simplifying the mechanism needed to transfer torque from the gearbox to the Block M and reducing the likelihood of tipping.

While this arrangement maintained the perspective effect in CAD models, we discovered when we set up the physical display that the alignment put the informational content too high relative to The Beacon. To solve this problem, we again reduced the height of the backdrop, this time to 40 inches.

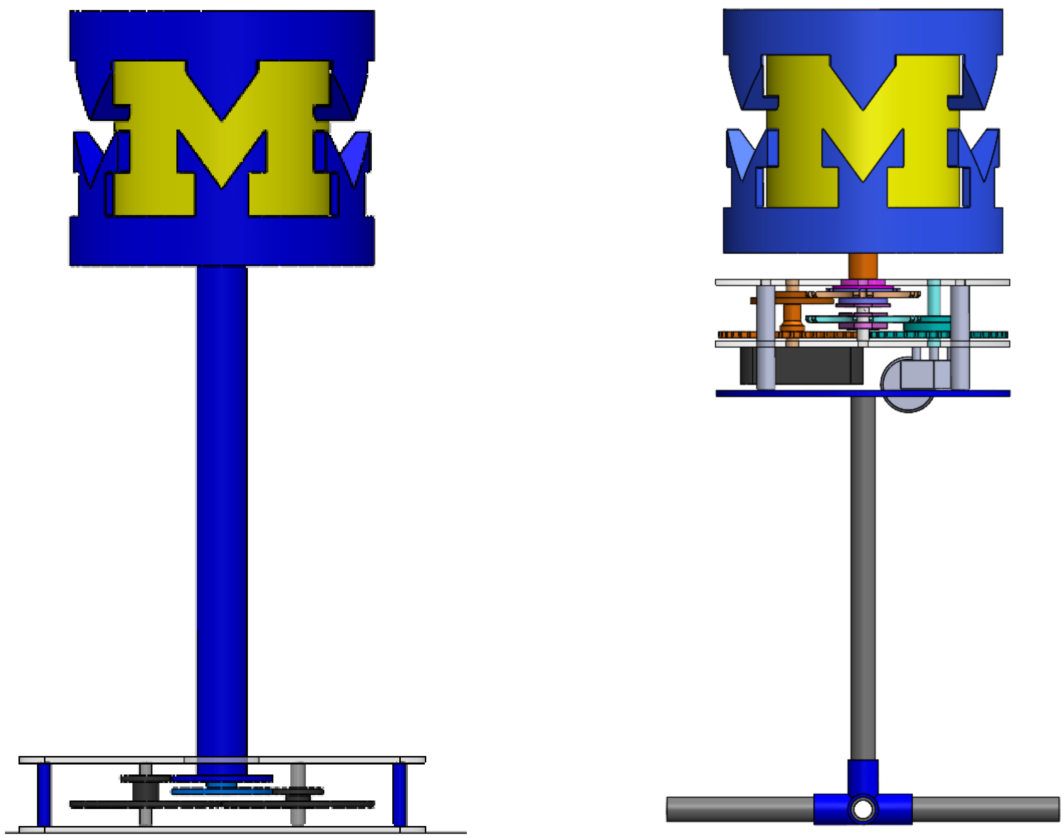
Stakeholder engagement drove several of the design decisions for the content of this display. Feedback from an existing sponsor indicated sign-up information should be extremely prominent and very simple to follow. ME Communications suggestions led to significant refinements to images, layout, color palette, logos, and fonts. Much of the content was refined with the help of course faculty.

In terms of mounting content to the panels, we had intended for some sections to be swappable to allow for the substitution of new information in the future, while logos and wordmarks were to have been "sewn-in," integral to the display and not able to be changed. However, determining which information was liable to change proved difficult, so to be safe, we have simply paired each panel with a removable poster, with updates to the poster design to be made digitally and re-printed, rather than exchanging smaller subsections.

FINAL DESIGN DESCRIPTION

Final Design - Mechanical

Some aspects of the display have changed significantly since the original concept and build design. The concept originally used coaxial shafts to support and extend the Beacon vertically to eye height. We chose to improve numerous aspects of the design by elevating the Beacon using a separate system we are referring to as the "pedestal". The pedestal provides height elevation for the Beacon while decreasing the distance between the Beacon and its gearbox. This improves the mechanical rigidity of the design while also enabling modularity and flexibility in the base of the entire assembly, improving packaging. Figure 19 shows two earlier designs of The Beacon.



(a) (b)

Figure 19: (a) DR2-maturity Alpha design. (b) Final Design concept with early-revision pedestal

With the intent to integrate lighting into the rotating Beacon, one of the first challenges we confronted when crafting the Final Design was electrical wire management. Because the baseplate is stationary while the Beacon rotates, a traditional electrical wire that runs from one to the other would be wound around the coaxial assembly and snapped when the display runs in one direction for a few rotations. This disabled the functionality of the lighting until we found a solution to isolate and separate the electrical lighting of the Beacon from the rest of the structure.

To address this issue, the team investigated two options: using a battery-powered light in the Beacon and implementing a slip-ring to continue doing a run through the coaxial assembly.

A battery-powered light in the beacon must last for 8 hrs of runtime a day, be independently transported as part of the presenter's carry-on luggage due to air travel regulations, would require separate charging, and would add mass to the highest point in assembly, increasing tipping risk. Alternatively, slip-rings are traditionally used to transfer electrical signals through rotary joints. Slip-rings function using brushes akin to brushed electric motors. A slip-ring within our budget, dimensional, electrical, and timeline constraints was sourced [66]. The slip-ring was chosen as our favored solution to the lighting wiring problem due to its minimal impact on other aspects of the machine design and low maintenance requirements.

The co-axial Geneva mechanism needed to receive a few updates from the Build Design maturity state. Electrically, the Final Design mechanism integrates a motor, and it must package a slip-ring into the co-axial assembly. Additionally, the Build Design used unibody 3D-printed gears and cams for the Geneva mechanism; however, the Final Design constructs these components from acrylic laser-cuttings for improved cosmetics. Finally, the Geneva mechanism has to support greater weight from a cosmetically-complete and lighting-integrated Beacon, so a supplementary structure was designed to support the co-axial shafts. An image demonstrating the critical design aspects of the Final Design mechanism may be found in Figure 20.

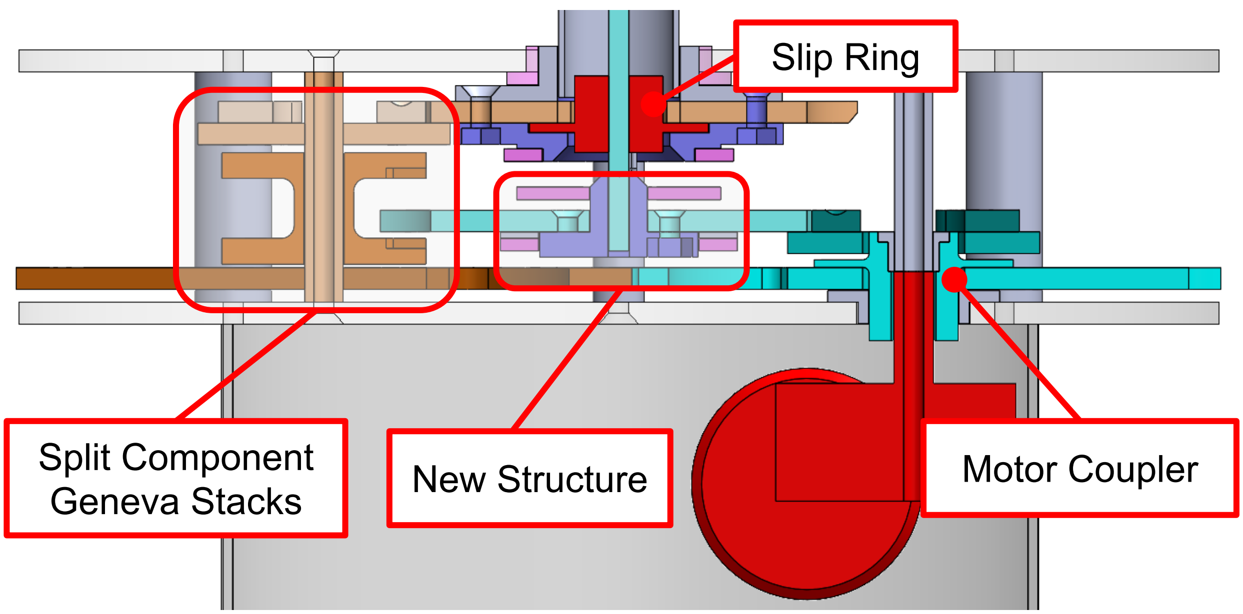


Figure 20: Cross section of the final coaxial Geneva mechanism design. Callouts detail new CAD additions. Additional views and labels may be found in Appendix E.

As shown in Figure 20, new bearing-locating base plates were designed to reinforce the axle and mechanism structure. The off-the-shelf sourced slip ring is packaged inside the exterior axle, attached directly to the Geneva wheel. The motor directly drives the lower Geneva cam shafts, coupled to the mechanism components with a 3D-printed coupler and D-shaft interface. The updated iteration of the Geneva cams and wheels splits these components into laser-cut and 3D-print multi-part, bolted subassemblies.

The execution of the “maize lamp shade” of the Beacon was important since it would be one of the main aspects that draws viewers’ attention. We looked for a light-diffusive, maize-tinted, thin walled tube, but were unable to find a direct solution off the shelf. As discussed in the Engineering Analysis, we addressed this challenge by cutting a polycarbonate tube to length and wrapping the tube in a light diffusive window film [67], as well as a maize-tinted vinyl sheet [68]. The film diffuses the LED light to remove hot spots, as well as hide inner components of the beacon. The tinted external sheet gives the Beacon its iconic maize color for the Block M. The application and function of these films is demonstrated in Figure 21.

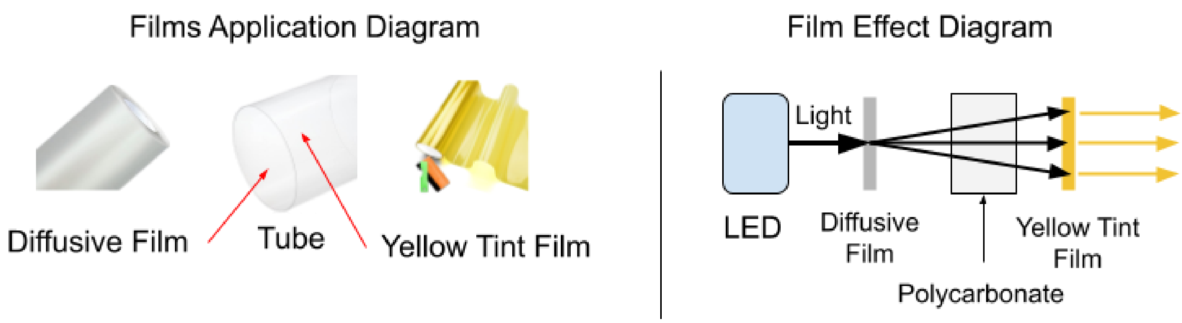


Figure 21. Two diagrams demonstrating the lampshade design and lighting interaction.

Final Design - Electrical

The electrical system is constructed using off-the-shelf components and custom wiring. We began our search for motors seeking out a motor that was optimized for low noise and high torque. We found that brushless motors would be best for this application [68]. Additionally, we wanted an option to control the speed of the motor, and a power supply that could plug directly into a wall outlet or power strip, to improve ease-of-use for the operator. With this in mind, we found a motor system that had everything we were looking for: a brushless 24V DC motor packaged with a power supply and wall plug, DC barrel connector, potentiometer-controlled speed, and a forward-reverse-off switch [69]. Knowing we were working with a 24V motor, we then sourced 24V lights so that we could potentially commonize the electrical system power supply. An LED light strip would be an optimal lighting package, as we could wrap it around a cylindrical structure inside The Beacon and easily achieve even coverage to minimize lighting hot-spots. We found a bright (2000 lumens), warm white (3000K) 24V LED strip that fulfilled these requirements [70]. The lighting system came with its own power supply and dimmer so we could test the system in isolation. The wiring diagram for our system is illustrated in Figure 22.

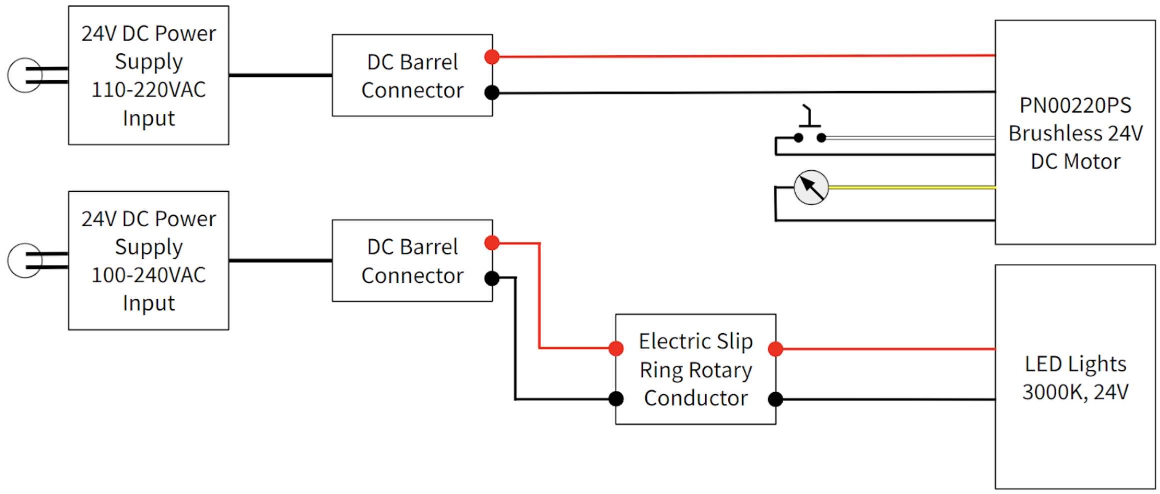


Figure 22. Wiring diagram for our electrical system. Note we are using a power supply to plug directly into a wall or power strip outlet for both the motor and lighting systems, which leads to our DC barrel connectors for each system. Our motor is brushless to optimize for low noise and is equipped with a forward-reverse-off switch, as well as a potentiometer to control the motor speed. Our lighting system is equipped with a dimming knob that is able to control the brightness of the lights, as well.

Final Design - Informational Backdrop

Providing a visual backdrop for the central device is our informational display. This backdrop comprises three panels, each aligned with a different viewing angle of The Beacon. In the areas immediately surrounding The Beacon are modular panels displaying factoids about the program, examples of past projects [71, 72], and images of our design at different stages of development. Above these, at a height visible without obstruction from The Beacon, we showcase core concepts of the program and practical benefits for sponsors, displayed in an attention-grabbing, easily-digestible manner. The design of the informational backdrop is shown below in Figure 23.

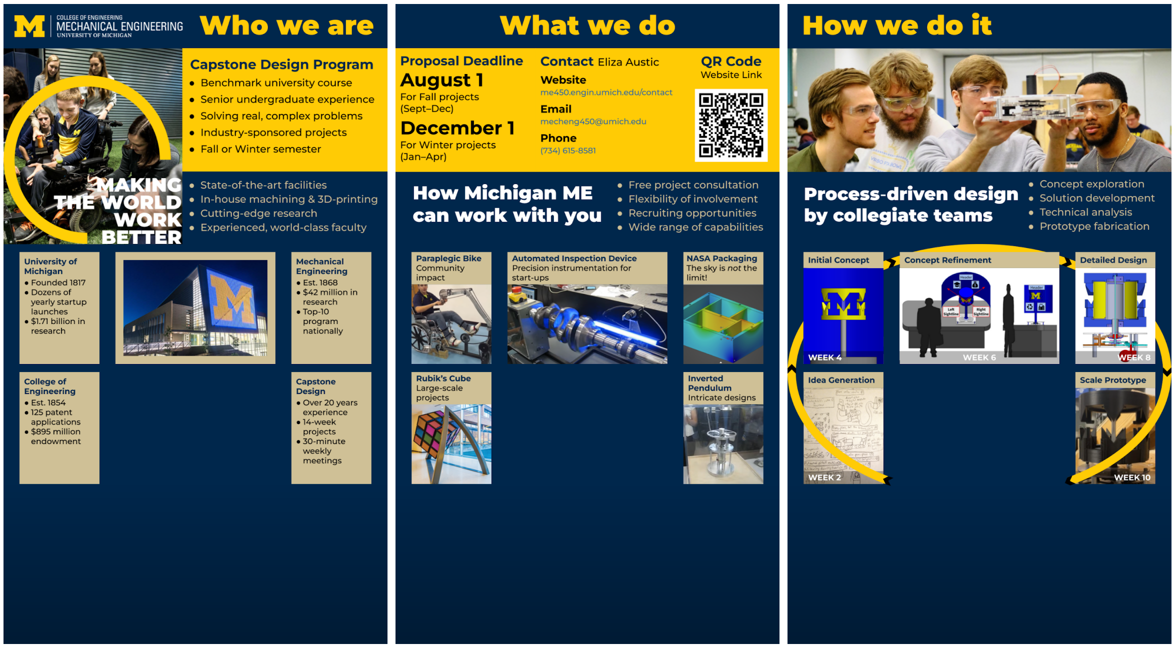


Figure 23. The design of the informational backdrop. The left panel provides information on the University, the College, the Department, and the course, expressing broad visions and communicating relevant facts [73]. The center panel provides practical information for sponsors, including when and how to sign up, the benefits to clients, and examples of past projects. The right panel provides a more in-depth look at the design process used in ME 450, using The Beacon to take viewers through multiple stages of design. Larger images of each panel can be found in Appendix F.

Because the text of the display is in English, viewers may perceive an implied left-to-right flow of information. To meet this expectation, there is a trend from general to specific, moving from information about the Department, through information about the course, to information about the project. In addition to this flow, there is also an expectation that the most important information be in the center, which aligns well with the previous structure because information about the course is the most vital for potential sponsors.

Final Design - Manufacturing

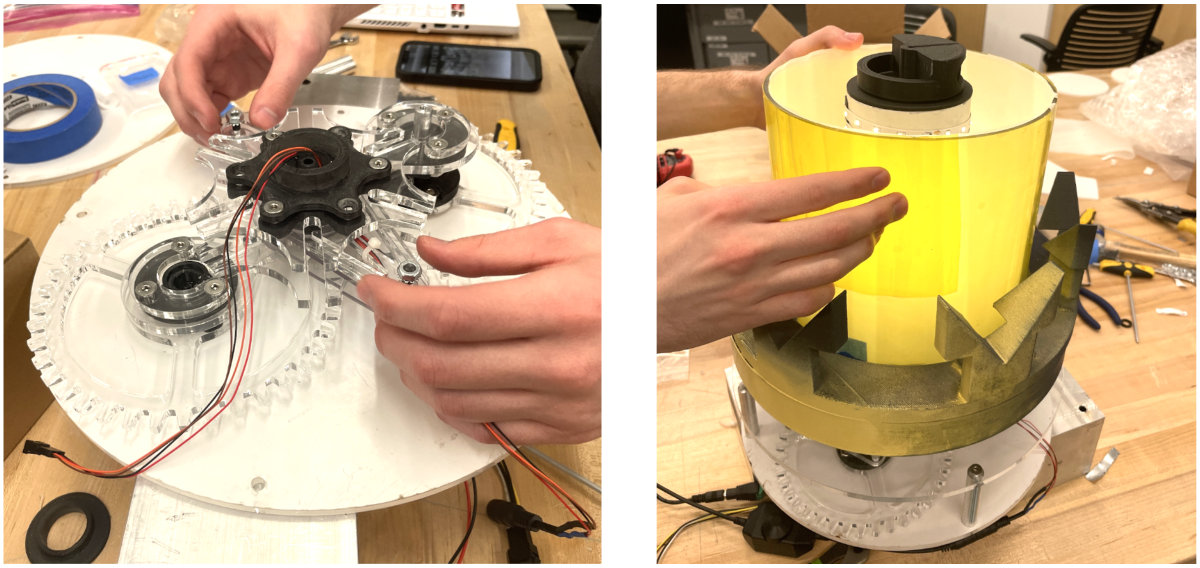
Manufacturing our display encompassed two weeks of our project timeline. Workload was distributed across the group by isolating significant components of the display and assigning different team members to complete them in parallel. Generally, two members worked on the fabrication and assembly of The Beacon, one member worked on the time-intensive finishing process on the M halves and maize lamp shade, and one member designed and constructed the informational backdrop. In progress assembly photos may be found in Figures 24a and 24b.

The Beacon's mechanical assembly had the most parts and critical fits of all display components, justifying the extra member allocated to its construction. All components were manufactured by the team using the machines and materials specified in Table 15. During assembly, minor kinematic interferences were found between some components due to the lower tolerance capability of 3D printing versus preferred, longer lead time manufacturing methods like CNC machining. To remedy these issues, some spacer designs were adjusted to include intentional gaps between close-fitting, kinematic components. Given the higher tolerance capability of laser-cutting, the dry-contact rotary interfaces functioned smoothly with our manually-turned POM bearings, which were held to a -0.005 in / -0.010 clearance in on their outer diameters.

Table 15. Summary of component manufacturing process selection results.

Component Subcategory	**Part Examples**	**Long Lead-Time Process (preferred)**	**Short Lead-Time Process (chosen)**
Complex 3D	Block M halves Lighting structure Fittings	Aluminum CNC milling Anodized finishing	PETG 3D Printing Sanding and paint finish
Aesthetic	Geneva wheels Large Gears Baseplates	Aluminum CNC milling Polishing	Acrylic Laser-cutting No finish
Structural	Spacers Axles Bearings	POM & Aluminum CNC turning Polishing	POM & Aluminum Manual lathing No finish
Graphic Display	Easel/stand Printed graphic	Custom printed expandable graphic	Printed paper adhered to board 3D printed brackets

The rotary Block M halves were fabricated from PLA on large format 3D printers. Due to the size of the components, a large nozzle diameter was used to decrease the print time, but this also resulted in very visible layer lines. Given that these components are the centerpiece of The Beacon, they were smoothed by hand using sandpaper to remove the layer lines and produce a clean finish on the outer surface. The components were then coated using three layers of spray paint: primer, color, and matte clear coat. The two films of the maize lampshade were both cut to size using generic scissors, but adhered using different methods. The external yellow film had a pre-applied adhesive backing which directly attached the vinyl to our polycarbonate tube. The internal diffusive film was periodically taped to the tube surface around its circumference.



(a) (b)

Figure 24. (a) In-progress assembly of gearbox mechanism. (b) In-progress assembly of Beacon & lampshade assembly.

To create the informational backdrop, 3/16” foamboard was cut into the appropriately-sized panels using a craft knife. Posters with the content of the backdrop were printed and attached to the panels using rubber cement, to allow for a strong bond and easy removal in the event of new content being desired in the future. Because the backdrop requires multiple panels to fit in a suitcase, a method of fastening the panels is necessary. To that end, we 3D printed brackets to constrain the geometry of the panels relative to one another and glued each bracket to one panel to ensure ease of assembly and maintain structural rigidity.

A thorough description of the fabrication process of our display can be found in Appendix G.

VERIFICATION AND VALIDATION

Once our design was fully constructed, we had to verify that it actually meets the specifications that we set forth. These specifications are what we deemed necessary components of the design to answer our problem statement based on stakeholder engagement, benchmarking, research, and analysis. This is why it is crucial that we have a method of verifying every single one of them. Since every member of our group spent an adequate amount of time understanding different methods of verification for our design, we are confident that the ones we selected yield the best results in the simplest manner. Table 16 contains all of our methods and results and can be seen below. Note that some of the specifications have been given the result “Pending” due to us running out of time this semester to test them ourselves, but we have plans in place for how to test them.

Table 16. Requirements and Specifications along with their verification tests and results.

Display component	Rank	Requirement	Specification	Verification Test	Result
Overall display	1	Passes applicable regulations for commercial air travel	Does not contain any air-illegal substances	Inspection	**Passed**
	2	Can fit in a checked bag on commercial flights	Dimensions < 62 linear inches	Virtual and physical testing	**Passed**
	3	Comfortably transported/assembled by one person	Individual Lift Weight < 21.8 pounds Total Travel Weight < 50 pounds	Physical test and trial	**Passed**
	4	Compatible with range of event tabletops	Footprint < 30" x 72"	Virtual and physical testing	**Passed**
	5	Event setup needs to be reasonable	< 10 minutes assembly time	Empirical trial	**Pending**
	6	Can be fabricated within the ME 450 project budget	≤ $650 material cost	Inspection	**Passed**
	7	Repair needs to be reasonable	1 person needed < 60 minute repair time	Empirical trial	**Pending**
	8	Repair parts or services need to be easy to find	100% of fasteners purchasable off-the-shelf 100% of custom parts can be manufactured at U of M	Inspection	**Passed**
Aesthetic component	9	Draws people into ME booth	≥ 1 lighting element ≥ 1 brightly-colored element	Inspection	**Passed**
	10	Can keep a person's attention while presenter talks to someone else	≥ 1 moving element	Inspection	**Passed**
	11	Can draw and keep attention passively	100% of other aesthetic specifications are met without interaction	Inspection	**Passed**
	12	Device must run for duration of daily tradeshow presentation	> 8 hour runtime	Physical test	**Failed**
	13	The device must present no safety hazards while in operation	Tipping Force > 7.21 pounds [35]	Theoretical analysis and physical test	**Pending**
Informational Component	14	Form of backdrop integrated with device	All viewing angles align with informational content	Virtual and physical testing	**Passed**
	15	Demonstrates ME 450 core concept	≥ 3 previous ME 450 projects for reference ≥ 1 mention of value proposition	Inspection	**Passed**
	16	Appeals to forward-thinkers	≥ 1 previous socially-conscious ME 450 project for reference	Inspection	**Passed**
	17	Shows multiple stages of a design	100% of design stages shown for central device	Inspection	**Passed**
	18	Information can be updated as needed	100% of information is communicated through swappable modes	Physical test	**Passed**
	19	Branding aligns with other communications	100% of graphical elements meet Department style guidelines	Inspection	**Passed**
	20	Explains what the device is and what it does	100% of our device's mechanical design innovations introduced	Inspection	**Passed**

Overall Display

- *Does not contain any air-illegal substances:* Inspection. As we acquired the parts needed to create our entire display, we made sure that everything passed the guidelines set forth by the FAA. After the final display was constructed, we double checked to make sure that everything remained within guidelines. Result: Passed.
- *Dimensions < 62 linear inches:* Virtual testing and physical testing. The entire display was virtually packaged within dimensions that represent our suitcase. This allowed us to confirm that the idea we had in mind had potential to fit inside a real-world case that passes regulations. Additionally, we conducted physical tests once our design was brought to life. Result: Passed.
- *Individual Lift Weight < 21.8 pounds; Total Travel Weight < 50 pounds:* Physical test and trial. Every component that will have to be lifted individually by the presenter was weighed on a scale to confirm that each one was under 21.8 pounds. We then placed every component of the display inside of our suitcase along with the foam inserts and measured the total weight, maintaining the 50-pound weight limit. Finally, we ran a trial with our presenter to be sure she could lift each individual component safely. Result: Passed.
- *Footprint < 30” x 72”:* Analysis and physical test. Using CAD, we placed the model of the design on a representative surface with these dimensions to be sure the footprint was small enough. When the physical model of the display was complete, we physically tested our display in an area with these dimensions to confirm our footprint. Result: Passed.
- *< 10 minutes assembly time:* Trial. Each member was supposed to attempt to assemble the display within the timeframe. Once we were all confidently able to do so, we planned to have our presenter attempt to assemble the display as well to make sure they could do so comfortably within time. We got our final piece for our informational backdrop too late in the semester to run complete trials. However, preliminary trials with our presenter indicate that the complex assembly process for the central device takes 7 minutes, so we are confident this specification can be met with the relative simplicity of the backdrop. Result: Pending.
- *≤ $650 material cost:* Inspection. As parts were bought, we maintained an active bill of materials to keep track of where all of the money was going so we always had an idea of how much money we had remaining. We did need to get approval to extend our budget beyond the standard $400. Result: Passed.
- *1 person needed; < 60 minute repair time:* Trial. Based on our experience with the model, common points of repair were identified, and we had planned to have each member attempt to replace that part alone, within 60 minutes. However, we did not have time to perform this trial by the end of the semester, especially as it would likely require breaking pieces and fabricating additional ones. However, given the access to skilled

professionals at University facilities, we anticipate much real-world repair to go fairly smoothly for our presenter. Result: Pending.

- *100% fasteners purchasable off-the-shelf; 100% of custom parts can be manufactured at U of M:* Inspection. To be sure that parts are easily accessible for the future, we made sure that the fasteners are easy to buy online or in-store and that all of the custom parts that are needed can be made here at the University. Result: Passed.

Aesthetic Component

- *≥ 1 Lighting element; ≥ 1 bright color:* Inspection. We visually confirmed that our lighting element was, in fact, working and that the color of The Beacon light was easily identifiable as maize. Result: Passed.
- *≥ 1 moving element:* Inspection. We visually confirmed that the gears could be seen rotating through the acrylic base plate and that both the upper and lower parts of the “M” were rotating in unison but in opposite directions. Result: Passed.
- *100% of other aesthetic specifications are met without interaction:* Inspection. Visually confirmed that the final display did not require viewers to interact with it to meet aesthetic goals. Result: Passed.
- *> 8 hour runtime:* Physical test. We planned to power and run the device for over 8 hours straight. This would have allowed us to confirm that it could operate during the entire duration of a typical 8-hour tradeshow day. After running for about 3 hours at the Design Expo, though, the 3D print that was mounted on the motor wore out too much to rotate the “Block M”. The 3D print was replaced, but a more permanent solution is needed. We hope to have one in time for project hand-off, but at the time of this writing, that solution has not been fabricated. Result: Failed.
- *Tipping Force > 7.21 pounds:* Analysis and physical test. Analytical methods were used to determine what force was required to tip over our central device. Since our tipping force was found to be approximately 8 pounds, our device theoretically should not fall when a force of 7.21 pounds is applied. To confirm this, we planned on using a force gauge to simulate this “poking” force and test if our design tipped over. Unfortunately, we ran out of time in this semester before we could test this ourselves. However, because of the results of our theoretical analysis, we are confident this test can be passed. Result: Pending.

Informational Component

- *All viewing angles align with informational content:* Physical test. We set up the completed final design and aligned the informational components with the central device until everything could be seen adequately. This was a good test because the presenter will have to do the same thing when she is at tradeshows. Result: Passed.
- *≥ 3 previous ME 450 projects for reference; ≥ 1 mention of value proposition:* Inspection. Visually confirmed that there were 3 previous projects that are relevant to

what companies are involved with. Also confirmed that there were benefits for potential sponsors listed and clearly stated. Result: Passed.

- *≥ 1 previous socially-conscious ME 450 project for reference:* Inspection. Visually confirmed that there was at least one past ME 450 project that was regarded as being socially-conscious. Result: Passed.
- *100% of design stages shown for central device:* Inspection. Made sure that the progress of our central device was represented and could be followed without explanation. Result: Passed.
- *100% of information is communicated through swappable modes:* Physical test. Physically attempted to change the information on the display. Result: Passed.
- *100% of graphical elements meet Department style guidelines:* Inspection. While the informational component was being created, we made sure the branding guidelines were being followed. Once the component was complete, we double-checked that everything was in-line. Result: Passed.
- *100% of our device's mechanical design innovations introduced:* Inspection. Confirmed that the major design innovations were showcased on the display. Result: Passed.

Validation

Looking at validating our display, we want to confirm that The Beacon is something that addresses our design problem. This includes being sure our display can gather attention, showcase our capabilities, attract engineers and management, convey ME 450 information, and drive engagement with the ME department. On paper, our design should be able to achieve these tasks since we have verified that it fulfills the requirements and specifications that we deemed were necessary for doing so. However, reality is often not what it seems, so we believe it was necessary to test our design in a setting similar to the tradeshows and conferences it will be utilized in. The best way for us to do this validation within the timeframe of this course was by taking advantage of the Design Expo that occurred on April 13, 2023. At the Design Expo, there were other booths and tables with different types of display seeking to do similar things to what we aim to do. This allowed us to actively witness how well our design performs, especially with other groups who were essentially competing for attention.

Additionally, we offered a survey to those who saw our display to get further information on how well we performed in each of the goals above. There were four questions about our display: "What was your initial reaction to this display?" "Would this display effectively keep you engaged without a presenter?" "What effect does this display have on your perception of the ME Department?" and "If you were a corporate representative, would this display entice you to work with the ME Department?" The responses to these questions were, respectively, 100% said "Positive," 100% said "Yes," 96% said "Positive," and 92% said "Yes."

Unfortunately, from some questions to get a sense of our audience, 23/26 respondents were students, and none were faculty, staff, or ME 450 sponsors. Although this sample does not provide a representative perspective of our intended audience, the data from the first two questions still provides an indication that our display is successful in attracting positive attention and continuously engaging viewers.

DISCUSSION

If we had more time to validate our design, we would actually test bringing our display to tradeshows to see the intended audience's reactions to it. Ideally, we would ask them to comment on both The Beacon as well as the informational backdrop. This feedback would allow us to make any modifications to The Beacon design or the informational backdrop content and/or design.

Problem Definition

If we had more time and resources to collect data and better define the problem for our project, we would engage with more current, former, or potential ME 450 project sponsors and ask them what they would like to see in a display that would entice them to work with us. Additionally, we would reach out to more of the ME 450 faculty to ask what information about ME 450 is critical to present in the display.

Design Critique

There are four types of critical issues with The Beacon's final embodiment which our team found inadequate. Mechanically, there are two kinematic interfaces which are not robust, and caused The Beacon to fail its running duration requirement. Finish-wise, the maize lamp shade and rotary M halves manufacturing solutions fit in our timeline, but ultimately don't look aesthetically impressive. Electrically, the wiring was quick to construct, however it is damage-prone and unintuitive for an untrained operator to use. Finally, the informational backdrop assembly solution was adequate for our team to assemble for the Design Expo, however, a solo-operator will have difficulty. Solutions to these critical issues are discussed later under Recommendations.

Non-critical issues with The Beacon do exist in the assembly process, integration with the informational backdrop, and representation of the University of Michigan. The long, thin internal shaft is difficult to align with its Geneva coupler and is in close proximity to the thin-gauge wiring of the slip-ring. Careful, skilled assembly is required to avoid accidentally breaking slip-ring or Geneva wheel supporting structure, and justifies a redesign of this interface. While the integration with the informational backdrop is successful when understood, the central device does block lines of sight to content. Finally, to achieve the forced perspective shape of The Beacon, concessions were made to the accuracy of the original Block M graphic. There exist fillets and maize-unfilled corners which reduce the sharpness and genuineness of the final product.

Risks

The most significant challenge we encountered in our design process was that our problem is very open-ended. As a result, it was difficult to establish concrete principles from which to approach crafting a solution. To address this issue, we engaged with varied stakeholders throughout the design process to determine what their needs are. Additionally, we spent a great deal of time and effort in the early stages of concept development to ensure we had sufficiently explored our wide solution space.

Another challenge we encountered was the fast pace of this project. Unusually, we are expected to deliver a finished product to our sponsor at the end of the semester. As a result, our analysis and fabrication needed to produce a fully real-world-ready product, necessitating higher standards of refinement and usability than are typical for projects of this timeframe. To address this issue, we established contingency plans to ensure our display would be at least partially functional, even if we had been unable to finish it to our intended design. Additionally, we designed it with ease of fabrication in mind, using off-the-shelf parts and automated processes wherever possible to reduce our workload and accelerate our pace.

We do not expect our end-user to face any significant bodily risks from our design. To ensure the ability to transport it by air, we have designed it to be lightweight, mitigating the effects of any tipping or dropping collisions. For the same reason, it is made without any chemically volatile substances. The mechanical design does not produce any motion fast enough to be risky. Additionally, we have determined through testing that even stopping the device while the motor is running will not result in a catastrophic failure; the failure point is the connection between the motor and the rest of the device, so a failure simply causes the motor to continue spinning harmlessly, not driving the mechanism. We have also verified that the device does not produce enough heat to pose a hazard, and it similarly does not draw a potentially-dangerous amount of electrical power.

The greatest risk we anticipate our display to pose to its end-user is a utilitarian one: There is a possibility that a significant failure could occur while our user is on the road, precluding her from continuing to use the display to attract clients. To mitigate this risk, we have designed it to allow subsystems to function independently of one another. If the backdrop is damaged, the mechanism can still draw attention, and if the mechanism fails, the backdrop can still provide continuously-engaging information. If either the motion or lighting system fails, the other one can remain fully operational, and even in the event of a pull power-failure, the display is designed to be aesthetic enough to be a conversation piece even while static.

REFLECTION

Global, Social, and Economic Impacts

Because the public will have direct access to our display, we have needed to ensure it does not pose a safety hazard. Therefore, we have made sure it does not contain volatile chemicals, does not draw potentially-dangerous amounts of electricity, is not heavy enough to be hazardous if it tips or is dropped, and will not involve high-velocity movement in normal operation or under failure.

Our project has produced a one-off final product which is not intended to be brought to market. Thus, it will not have any direct effect on the global marketplace.

In the same vein, our display is modest in size, so it will not consume much energy to manufacture, transport, or use, nor will it consume many resources or produce much waste in disposal. This is particularly true in light of the social context of our project: Supporting the development of competent, creative, ethical engineers will have a net positive impact on society.

If our project is successful, we may reduce the opportunities for engineering consultancy firms to get business, or for other colleges to complete similar projects. For the most part, though, ME 450 is a small-scale operation, and its effects on the market are similarly small.

As outlined in the “Stakeholder Analysis” section above, we have carefully considered the parties set to be impacted by our project, analyzed their roles through a stakeholder map, and conducted interviews to get their direct input.

Social Identity Impact on Project

Being a group of four, it is not surprising that each of us came from different backgrounds and had different life experiences leading up to this semester. Of course, this led to multiple different perspectives when it came to approaching problems and making decisions. Our differences allowed us all to take a step back and listen to each other as we shared our thoughts and beliefs and how they shaped what we were thinking. Once everyone was able to say their piece, we collectively thought of ways to compromise where we could to make the best decision for our stakeholders.

Considering another major player in this project, our sponsor Eliza’s experience and identity is quite different from our group’s. She does not, for instance, have a technical or mechanical background, but she does have a wealth of experience trying to attract project sponsors. Again, communication was key to making sure that these differences were not barriers. Meeting with Eliza once a week allowed us to stay in constant contact and integrate her into the decision making for our design process and final design.

Inclusion and Equity

There exists an interesting dynamic between the presenter and the viewers of our display. Because the viewers have something the presenter wants (funding to support ME 450 projects), they have leverage over her. As a result, it is important that we be aware of this power imbalance while designing our display. At the same time, we are experiencing another power dynamic of a different sort: We have a close relationship with our presenter, who is also our project’s sponsor, which gives us the opportunity to gain her direct input for some of our requirements.

Additionally, because we are representing the ME Department and the ME 450 program, faculty and staff have a stake in our project. This presents yet another power dynamic: Some of the people we are representing are also responsible for grading our work in this course. As a result, we have had to be careful to separate input regarding what would allow our display to best serve the department and what is expected of us within the framework of the course.

Thus, depending on the subject being discussed, we have had to prioritize different stakeholders. Input from current corporate ME 450 sponsors is the most important when it comes to the effectiveness of our display in attracting attention. The perspective of our presenter takes priority for practical matters of transport and assembly. The content of the informational backdrop was the subject of the most stakeholder input, with professors weighing in on the pedagogical philosophy of the course, our presenter helping us understand what would make her job easier, representatives from ME Communications expressing their ideas on how our display fits into the broader public-facing branding of the Department, and existing sponsors explaining how to prioritize information to be most effective at tradeshows. The task of synthesizing all these perspectives into a cohesive, aesthetic display has fallen to us, and our process has allowed us to take input from all of them in their respective areas of expertise.

Because each member of our team brought a different perspective and approached problems in different ways, there was sometimes conflict over the direction of this project. However, because of the multi-faceted nature of our problem, we were able to leverage these different approaches to increase efficiency, delegating tasks to individuals with the most expertise and comfort. Further discussion of this process can be found in the "Social Identity Impact on Project" section above.

Ethics

For our design to represent mechanical engineering, we thought it best to keep a lot of the gears and wheels within the mechanism visible for viewers. However, this leads to a potential safety issue since we decided to leave the sides of our gearbox open. When considering this design decision, we had to weigh the possibility of a person risking minor injury to their finger versus viewers getting the full mechanical experience of seeing how our device works so they can understand the benefits of partnering with ME 450. We believe the experience viewers will get is worth much more than the very unlikely finger injury that can be obtained. If this device were to go into the marketplace then this issue would have to be addressed, but it would only require a clear covering around the gearbox, something we did not have time or material to do. Additionally, our display was never intended to be brought to market, further mitigating this concern. Ethics like human safety are extremely important to all of us, the University of Michigan, and future employers, and we wanted to be sure we considered them with this project.

RECOMMENDATIONS

During our design validation, the team found that the motor coupler and top-M coupler failed after two hours, causing The Beacon to inconsistently rotate and slip in clocking.

The motor coupler relies on a shallow, D-shaped interface between the motor output shaft and 3D printed coupler. This failure stripped the D-shape flat on the 3D print, losing torque transfer capability to the Geneva mechanism. We propose replacing the 3D printed flat surface with an aluminum sheet insert, improving the contact stress capacity of the flat surface, consequently improving its durability. The top-M coupler relies on a friction fit with the internal steel shaft to transfer torque from the Geneva wheel to the top-M. Given the low friction interface between the smooth-ground surface of the shaft and PETG 3D print, the coupler began to slip in rotational clocking. Increasing the friction of the interface by scuffing the steel shaft surface or switching to a D-shape interface like the opposite side of this coupler would resolve the issue.

The maize lamp shade was constructed as a layered tube of polycarbonate and films so that we could create this unique, functional component in a very short lead-time and within budget. The resulting component functions and fulfills our requirements, but it suffers from visible split lines, tape, and adhesive air-bubbles, all of which detract from the aesthetic quality of the component. We propose that this component is redesigned entirely. One potential solution is to reutilize the existing lampshade film architecture, but apply the films using a painting process rather than lamination. Another option could be to extrude or mold a custom, translucent, maize-colored plastic tube which accomplishes the component function with a monocoque construction.

The chosen electrical components and electrical wiring successfully enabled the motion and lighting functions of The Beacon. However, the system includes redundant power supplies, includes redundant connectors, is exposed to wear over time, and has unlabeled controllers. The power supplies and DC barrel connectors for the motor and lights can be commonized, providing a single plug and reducing the effort and setup requirements for the system. A dedicated control box could be designed and packaged underneath The Beacon's gearbox. This would protect the wiring from snagging during transportation/assembly and provide a static location to install the light/motor control knobs with opportunity for aesthetic labeling.

Like many of the components of our display, the informational backdrop was made from off-the-shelf and 3D printed parts. In particular, the panels are generic foamboard, the brackets are PETG 3D prints, and the posters were printed in-house on standard paper. Because of the late start to the design of the backdrop (due to reasons outlined in the Design Process section above), we did not have time to iterate these pieces. As a result, we discovered too late that the 3D printed brackets were not tight enough to effectively clamp the foamboard, and due to manufacturing and handling variations in the latter, designing the interface tighter would've made assembly difficult with the rigid material of the brackets. Additionally, in order to get the posters printed quickly and avoid having to spend money on a commercially-produced custom product, we printed them on standard paper, necessitating additional fastening to the panels. These factors combined to make our Design Expo assembly very cumbersome, with masking tape used to hold the brackets in place and binder clips used to attach the posters. The process of assembling the backdrop required at least two people and over 20 minutes. To alleviate these issues, we suggest printing the content directly onto the panels and designing a custom clip which utilizes an elastic mechanism to hold the panels rather than a friction fit.

CONCLUSION

We have determined that "The University of Michigan Mechanical Engineering Department does not have a tabletop display to gather attention and showcase its capabilities at tradeshows and conferences. We need to create a "wow-inducing" display that attracts industry engineers and management to our booth, conveys information about ME 450, and drives engagement with the ME department. The end goal of this engagement is to draw positive attention to the program, not just as an educational endeavor, but also as an accessible design resource for public and private entities." Our main objective is to increase the number of sponsors for future ME 450 projects. We have developed a project-focused model of a procedural yet solution-oriented design process that we have applied to our project. This has allowed us to remain fluid with the types of procedures we used throughout the semester.

Researching other displays, marketing psychology, air-travel policy, and workplace regulations, we found our display should be interactive, colorful, and well-lit, while also following NIOSH and TSA guidelines. We found CEOs and start-up companies as the primary audience of the display, donors and company engineers as the secondary audience, and potential students and faculty as the tertiary audience. The presenter of our display is also a primary stakeholder because of their extensive interaction with the transportation and ownership responsibility of the display. Using our background information and our interviews with Eliza, we have generated a list of requirements and specifications as seen in Table 4.

After establishing specifications, we began concept generation with two primary methods, divergent thinking and the 4 P's of Creativity, as well as additional practices like sketching and deferring judgment. Once this divergent process produced a large quantity of solution concepts, we began the convergent process of selecting one. We used screening and Pugh charts to determine that a kinematic sculpture was going to be our design concept. Since this concept is very broad, we had to refine our idea. 10 more ideas were created by decomposing functions of previous ideas and modifying them with design heuristics until a final alpha design was selected with the aid of a pros and cons list.

Our design concept, The Beacon, is composed of two rotating halves joined by a maize-tinted, illuminated internal surface. A negative image of the Michigan Block M is revealed when observing The Beacon from any of 3 different angles, which align with the informational backdrop behind it to create one cohesive display.

To ensure our Geneva mechanism worked correctly, we conducted a Prototype I phase, in which we 3D printed the gear system. This prototype was found to be successful and gave us confidence as we continued to refine the design. Following this, the team created a 50%-scale model of the main, "Block M" part of The Beacon as our Build Design to observe in real life how its forced perspective functions, if the chosen construction methods are adequate for the Final Design, and if the device as a whole is aesthetically interesting. The Build Design gave us confidence that when the design was scaled up to 100%, the mechanism and supporting mechanical components would be able to fulfill their associated functional specifications.

We conducted a packaging analysis to verify our design was able to fit into checked luggage for air travel and concluded we would have enough space to insert foam padding in addition to The Beacon and informational displays. Tipping calculations were performed to verify that our device is stable and remains safe during operation. Material analysis and selection were completed to confirm the design would operate as intended.

The Final Design consists of many different components, namely The Beacon assembly, shaft assembly, gearbox and baseplate assembly, and informational displays. A full-scale embodiment was fabricated and assembled for the Design Expo on April 13, 2023; this is pictured in Figure 25.

Figure 25. The complete, full-scale Beacon and informational backdrop assembly. Displayed at the Design Expo on April 13, 2023.

Once our design was fully constructed, we had to verify that it actually meets the specifications that we set forth. These specifications are what we deemed necessary components of the design to answer our problem statement based on stakeholder engagement, benchmarking, research, and analysis. This was why it was crucial that we had a method of verifying every single one of them. Refer to Table 16 in the “Verification and Validation” section for our testing results.

Through our initial validation at the Design Expo on April 13, 2023, we received an overall positive response to The Beacon. Viewers indicated they had a positive reaction to the display, thought it reflected well on the ME department, said it would keep them engaged without a presenter, and expressed that it would entice them to partner with ME 450 as sponsors.

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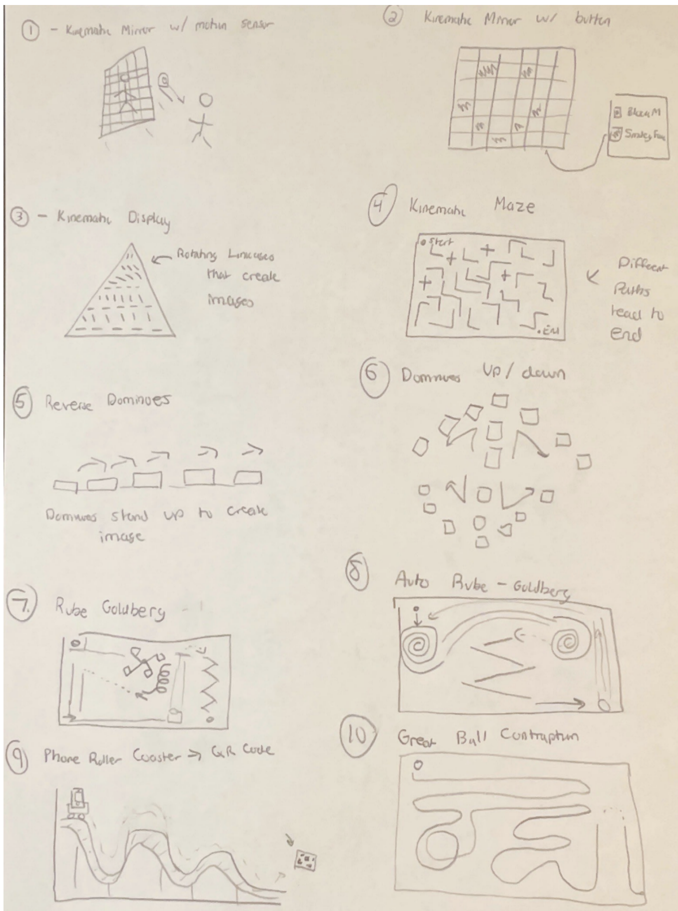
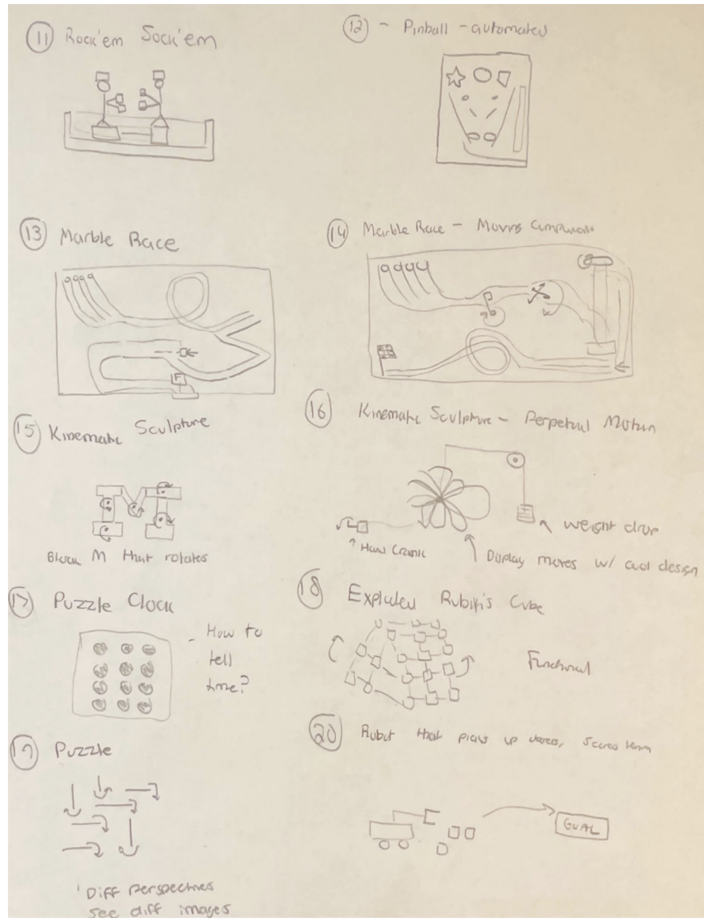
APPENDICES

Appendix A: Concept Generation

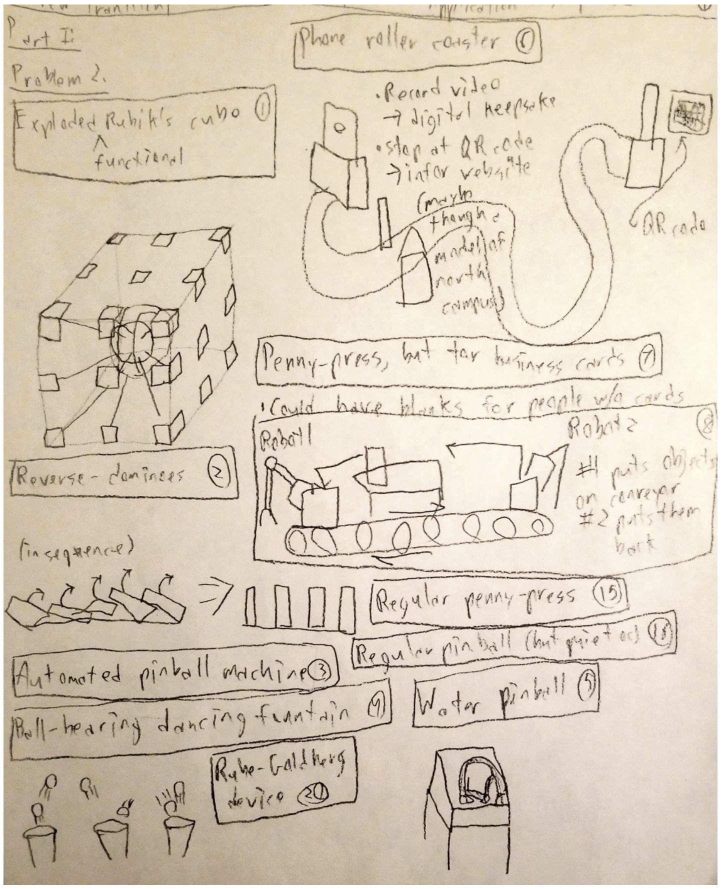
Each of our individual concept generation sketches.

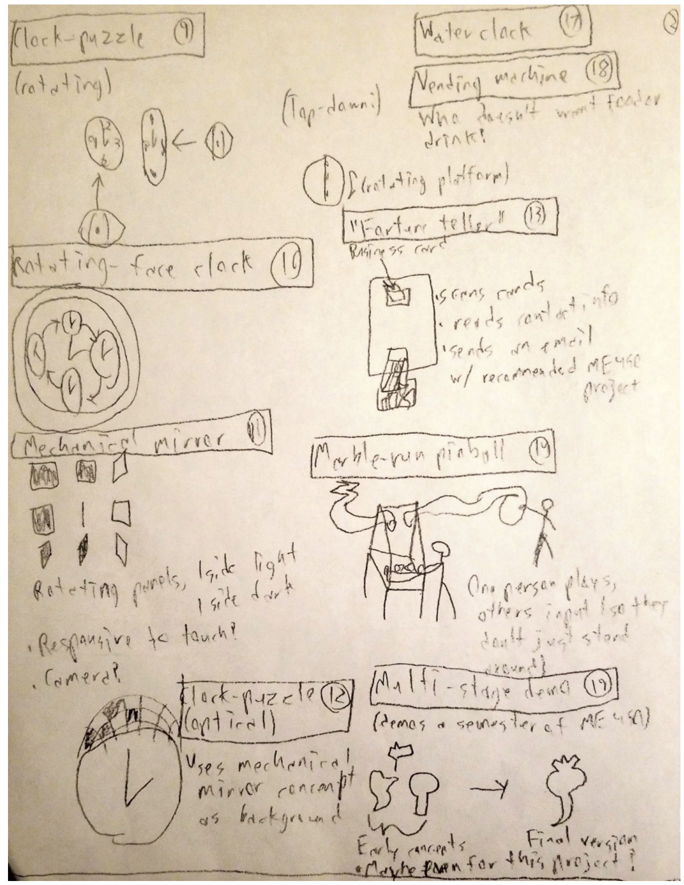
Evan



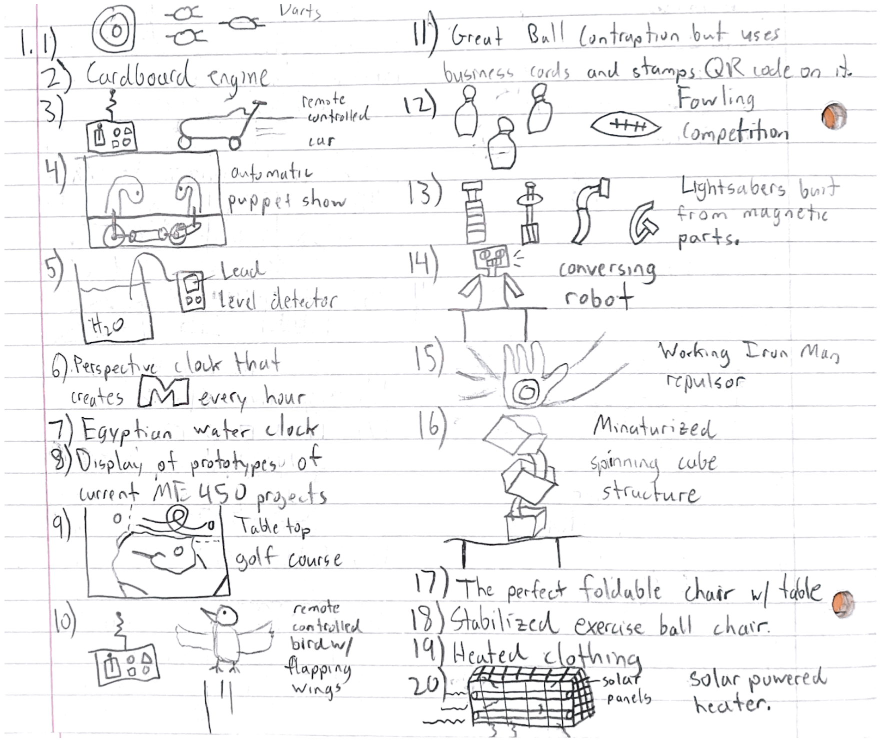


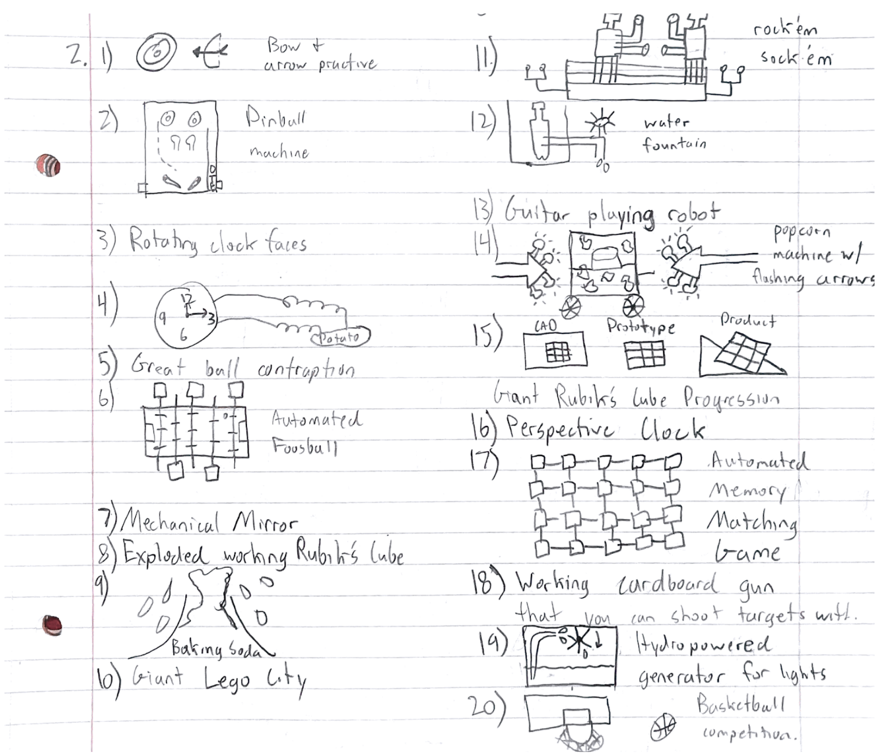
Andrew


Part I:
Problem 2.
Phone roller coaster (6)
Exploded Rubik's cube (1)
functional
·Record video
→ digital keepsake
·stop at QR code
→ info/website
QR code
Penny-press, but for business cards (7)
Robot 1
Robot 2
Reverse-dominoes (2)
(in sequence)
Regular penny-press (15)
Regular pinball (but print out) (16)
Automated pinball machine (3)
Ball-bearing dancing fountain (4)
Water pinball (5)
Rube-Goldberg device (20)

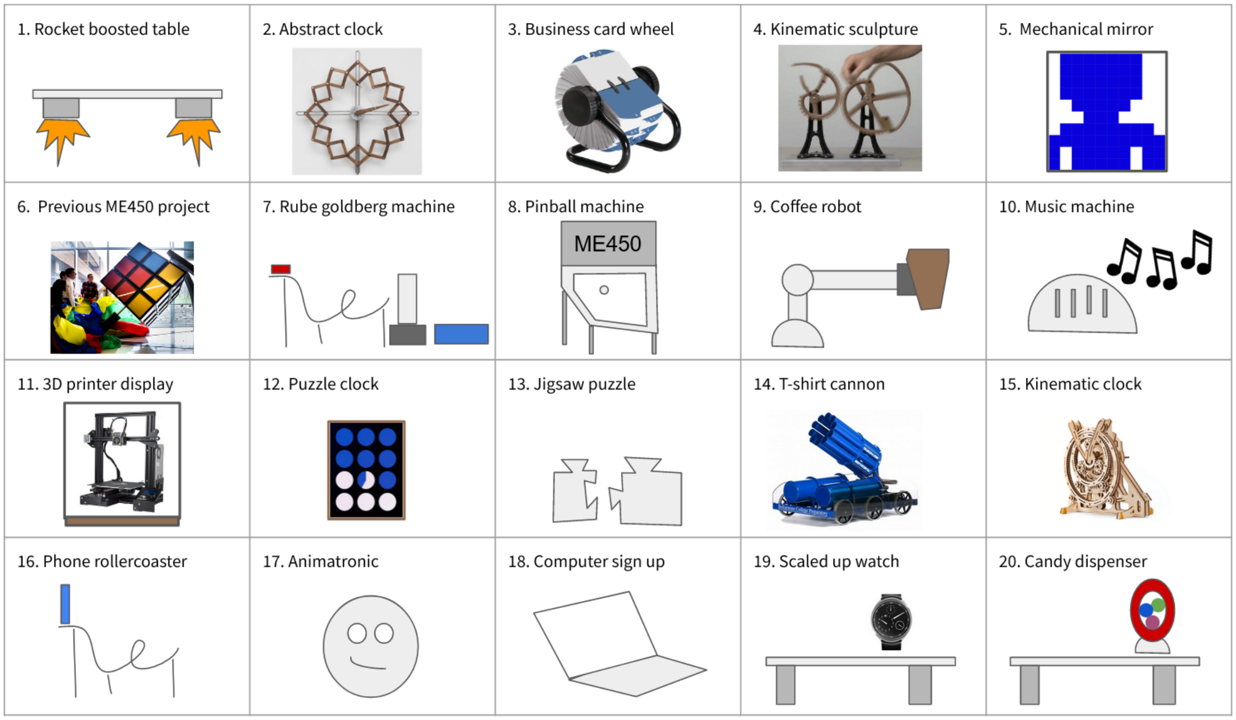

Clock-puzzle (9)
(rotating)
Water clock (17)
Vending machine (18)
Rotating-face clock (10)
"Fortune teller" (13)
Mechanical mirror (11)
Marble-run pinball (14)
Rotating panels, 1 side light 1 side dark
·Responsive to touch?
·Camera?
Clock-puzzle (12)
(optical)
Uses mechanical mirror concept as background
Multi-stage demo (19)
Early concepts
Final version

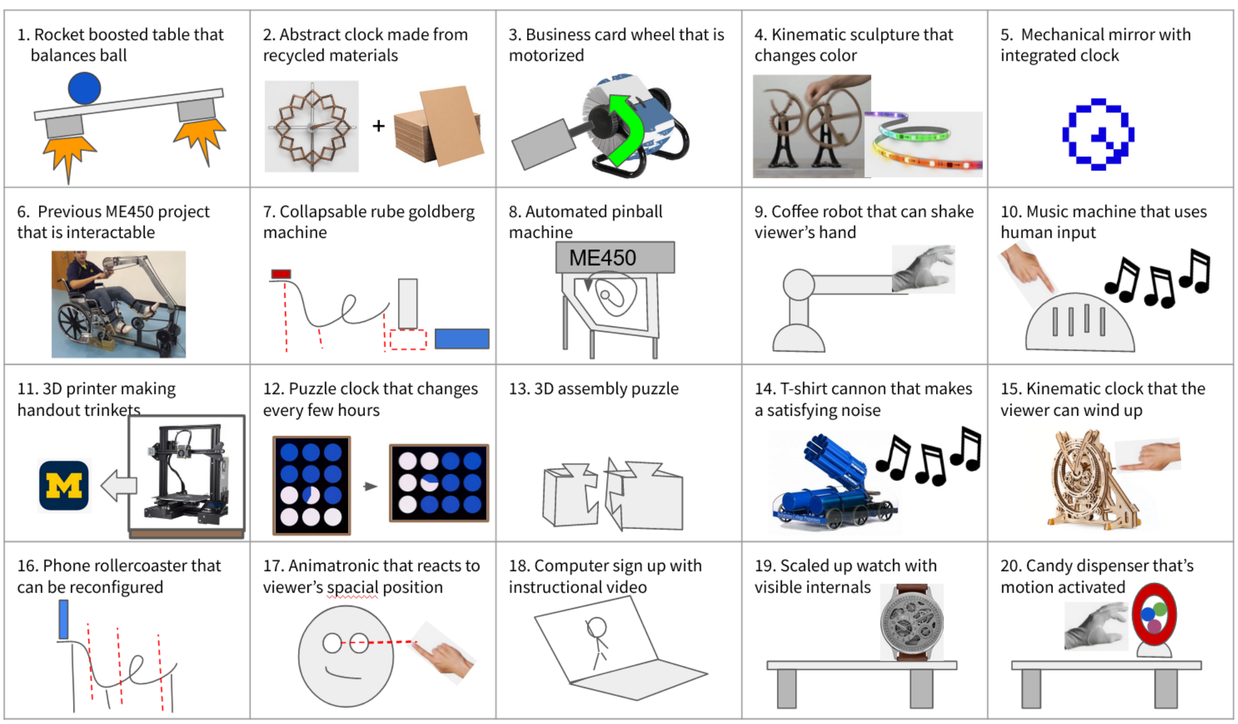
Tim


1. 1) Darts
2) Cardboard engine
3) remote controlled car
4) automatic puppet show
5) Lead level detector
H2O
6) Perspective clock that creates M every hour
7) Egyptian water clock
8) Display of prototypes of current ME 450 projects
9) Table top golf course
10) remote controlled bird w/ flapping wings
11) Great Ball Contraption but uses business cards and stamps QR code on it.
12) Fowling competition
13) Lightsabers built from magnetic parts.
14) conversing robot
15) Working Iron Man repulsor
16) Minaturized spinning cube structure
17) The perfect foldable chair w/ table
18) Stabilized exercise ball chair.
19) Heated clothing
20) solar panels
solar powered heater.


2. 1) Bow + arrow practice
2) Pinball machine
3) Rotating clock faces
4) Potato
5) Great ball contraption
6) Automated Fousball
7) Mechanical Mirror
8) Exploded working Rubik's Cube
9) Baking Soda
10) Giant Lego City
11) rock'em sock'em
12) water fountain
13) Guitar playing robot
14) popcorn machine w/ flashing arrows
15) CAD
Prototype
Product
Giant Rubik's Cube Progression
16) Perspective Clock
17) Automated Memory Matching Game
18) Working cardboard gun that you can shoot targets with.
19) Hydropowered generator for lights
20) Basketball competition.

Ricky


1. Rocket boosted table
2. Abstract clock
3. Business card wheel
4. Kinematic sculpture
5. Mechanical mirror
6. Previous ME450 project
7. Rube goldberg machine
8. Pinball machine
ME450
9. Coffee robot
10. Music machine
11. 3D printer display
12. Puzzle clock
13. Jigsaw puzzle
14. T-shirt cannon
15. Kinematic clock
16. Phone rollercoaster
17. Animatronic
18. Computer sign up
19. Scaled up watch
20. Candy dispenser


1. Rocket boosted table that balances ball
2. Abstract clock made from recycled materials
3. Business card wheel that is motorized
4. Kinematic sculpture that changes color
5. Mechanical mirror with integrated clock
6. Previous ME450 project that is interactable
7. Collapsable rube goldberg machine
8. Automated pinball machine
ME450
9. Coffee robot that can shake viewer's hand
10. Music machine that uses human input
11. 3D printer making handout trinkets
12. Puzzle clock that changes every few hours
13. 3D assembly puzzle
14. T-shirt cannon that makes a satisfying noise
15. Kinematic clock that the viewer can wind up
16. Phone rollercoaster that can be reconfigured
17. Animatronic that reacts to viewer's spacial position
18. Computer sign up with instructional video
19. Scaled up watch with visible internals
20. Candy dispenser that's motion activated

Appendix B: Concept Selection

Detailed below is our initial concept selection. It lists all of the unorganized designs, organizes them into clusters, removes duplicates, applies screening criteria, then does a second screening/evaluation parse to get to our top 7 concepts.

Evan

- Kinematic Mirror with motion sensor
- Kinematic mirror with button box
- Kinematic display
- Kinematic maze
- Reverse dominoes
- Dominoes up/down
- Rube goldberg - manual
- Rube goldberg - automated
- Phone roller coaster
- Great ball contraption
- Rock'em sock'em
- Automated pinball
- Marble race
- Marble Race - moving components
- Kinematic sculpture
- Kinematic sculpture - perpetual motion
- Puzzle clock
- Exploded rubik's cube
- Puzzle
- Robot that picks up blocks and scores them - controlled

Andrew

- Exploded (functional) Rubik's cube
- Reverse-dominoes
- Automated pinball machine
- Ball-bearing dancing fountain
- Water pinball
- Phone roller coaster
- Penny-press, but for business cards
- 2 robots picking up things, putting them on a conveyor belt, and taking them off again.
- Clock-puzzle (rotating)
- Rotating-face clock (optical)
- Mechanical mirror
- Clock-puzzle (optical)
- "Fortune teller" (business cards, recommended project, email)

- Marble-run / pinball (one person plays, others put them in)
- Regular penny-press
- Regular pinball (but quieter)
- Water clock
- Vending machine
- Multi-stage demo (demos a semester of ME 450)
- Rube-Goldberg device
- Multi-stage demo, but it morphs from one to another
- Penn-press produces lapel pin
- Clock puzzle, but instead of rotating, the numbers bend
- Presenter plays pinball, viewers put marbles in marble-run
- Dominoes continuously go up and down in a loop
- Make the clock face polarized and the flippy panels different colors
- Rubik's cube can go down to normal size
- Cut-away view of previous project
- Display runs off the table and onto the floor
- Upside-down ball-bearing fountain, with trampolines
- Organic curves & natural materials
- Wooden clock
- 6-ft dia. clock
- Spring-loaded mechanical mirror
- Hand-cranked business card stamping
- People walking by wind the clock
- Opening the case unfolds the device, like a pop-up book
- Dominoes INSIDE the pinball machine
- Business-card machine outputs them again from under the table
- Conveyor-belt pizza oven

Tim

- Bow and arrow practice
- Pinball machine
- Rotating clock face
- Potato clock
- Great ball contraption
- Automated foosball
- Mechanical mirror
- Exploded working rubik's cube
- Baking soda volcano
- Lego north campus
- Rock em sock em

- Water fountain
- Guitar playing robot
- Popcorn machine with flashing arrows
- Giant Rubik's Cube Progression
- Perspective clock
- Automated memory matching game
- Working cardboard gun to shoot targets with
- Hydro Powered generator for lights
- Basketball competition
- Dart Practice
- Cardboard engine
- Remote controlled car
- Automatic puppet show
- Lead level detector
- Perspective clock that creates M every hour
- Egyptian water clock
- Display of prototypes of current 450 projects
- Tabletop golf course
- Remote controlled flying bird
- Great business card contraption
- Fowling competition
- Saberlight building with magnetic parts
- Conversing robot
- Iron man repulsor
- Miniaturized GGB spinning cube structure
- The perfect foldable chair with table
- Stabilized exercise ball chair
- Heating clothing
- Solar powered heater

Ricky

- Rocket boosted table
- Abstract clock
- Business card wheel
- Kinematic sculpture
- Mechanical mirror
- Previous ME450 project
- Rube-goldberg machine
- Pinball Machine
- Coffee Robot

- Music machine
- 3D Printer display
- Puzzle clock
- Jigsaw Puzzle
- T-shirt Cannon
- Kinematic clock
- Phone rollercoaster
- Animatronic
- Computer sign up
- Scaled up watch
- Candy dispenser
- Rocket boosted table that balances ball
- Abstract clock made from recycled materials
- Business card wheel that is motorized
- Kinematic sculpture that changes color
- Mechanical mirror with integrated clock
- Previous ME450 project that is interactable
- Collapsable rube goldberg Machine
- Automated Pinball Machine
- Coffee robot that can shake viewers hand
- Music machine that uses human input
- 3D printer making handout trinkets
- Puzzle clock that changes every few hours
- 3D assembly puzzle
- T-shirt cannon that makes a satisfying noise
- Kinematic clock that viewer can wind up
- Phone rollercoaster that can be reconfigured
- Animatronic that reacts to viewer's spacial position
- Computer sign-up with instruction video
- Scaled up watch with visible internals
- Candy dispenser that is motion activated

SCREENING

- Clusters → Screening Criteria

Clusters:

- Mirror
  - Kinematic Mirror with motion sensor
  - Kinematic mirror with button box

    - Mechanical mirror
    - Spring-loaded mirror
- Kinematic Sculpture/Display
    - Kinematic display
    - Kinematic sculpture
    - Kinematic sculpture - perpetual motion
    - Case unfolds, pop-up-book-style
- Puzzle
    - Puzzle clock
    - Puzzle clock that creates M
    - Puzzle
    - Clock-puzzle (rotating)
    - Clock-puzzle (optical)
    - Numbers bend
    - Saberlight building
- Rube-Goldberg Like
    - Rube goldberg - manual
    - Rube goldberg - automated
    - Great ball contraption
    - Marble race
    - Marble Race - moving components
    - Reverse-dominoes
    - Phone roller coaster
    - Rube-goldberg device
    - Continuous, looping dominoes
    - Dominoes inside pinball machine
- Games
    - Rock’em sock’em
    - Automated pinball
    - Bow and arrow practice
    - Dart practice
    - Tabletop golf course
    - Robot that picks up blocks and scores them - controlled
    - Pinball machine
    - Fowling competition
    - Remote controlled car
    - Remote controlled bird
    - Automated memory matching game
    - Marble-run/pinball
    - Rock em sock em

    - Presenter plays pinball, viewers drop into marble run
- Art
    - Reverse dominoes
    - Dominoes up/down
    - Miniaturized GGB spinning cube structure
    - Ball-bearing dancing fountain
    - Water pinball
    - Lego north campus
    - Expanding-contracting Rubik's cube
    - Table extension over edge and onto floor
    - Upside-down ball-bearing fountain
    - Organic curve & natural materials
- Engineering demo
    - Exploded rubik's cube
    - Water fountain'
    - Working cardboard gun and targets
    - Hydro powered generator
    - Multi-stage demo
    - Morphing demo
    - Me 450 prototypes
    - Cut-away view
    - Iron man repulsor
    - Heated clothing
    - Solar powered heater
    - Cardboard engine
- Automated Robots
    - Automated pinball machine
    - Automated foosball machine
    - Conversing robot
    - Guitar playing robot
    - Conveyor-belt robots
    - Automated puppet show
- Souvenir factories
    - Penny-press, but for business cards
    - "Fortune-teller"
    - Regular penny-press
    - Lapel pin
    - Hand-cranked business-card stamping
    - Output slot under table
    - Pizza oven

- Clocks
    - Rotating clock faces
    - Potato clock
    - Egyptian clock
    - Rotating-face clock
    - Polarized face with mechanical-mirror backdrop
    - Wooden clock
    - 6-ft dia. clock
    - Foot-traffic-wound clock

Screening Criteria Applied:
- Packaging feasibility - (fits in checked bag, also fits on conference table)
- Dangerous things no-no
- Annoying noises no-no - (loud/annoying sounds from the display operating will be annoying to nearby tables and viewers)
- Illegal air travel substances no-no - (everything must be able to travel on commercial flights)
- ME focused
- Design feasibility
- Liability
- Gut check

Clusters with Screening (First Parse):
- Mirror
    - Kinematic mirror with button box
    - Spring-loaded mirror
- Kinematic Sculpture/Display
    - Kinematic sculpture - perpetual motion
    - Case unfolds, pop-up-book-style
- Puzzle
    - Numbers bend
    - Saberlight building
- Rube-Goldberg Like
    - Rube goldberg
    - Great ball contraption
    - Marble race
    - dominoes
    - Phone roller coaster
- Games
    - Rock'em sock'em

    - Tabletop golf course
    - Pinball machine
    - Remote controlled object
    - Automated memory matching game
    - Marble-run/pinball
- Art
    - Miniaturized GGB spinning cube structure
    - Expanding-contracting Rubik's cube
- Engineering demo
    - Exploded rubik's cube
    - Multi-stage demo
    - Cut-away view
- Automated Robots
    - Automated arcade machine
- Souvenir factories
    - Penny-press, but for business cards
    - Wearable
- Clocks
    - Rotating clock faces
    - Polarized face with mechanical-mirror backdrop
    - Puzzle-clock
    - Clock-puzzle

DOWN SELECTING TO "5-ish" DESIGNS
Clusters with Screening (Second Parse):table

- Mirror
    - Kinematic mirror
- Kinematic Sculpture/Display
    - Chaos → order through motion
    - Exploded Rubik's cube
- Rube-Goldberg-Like
    - Rube goldberg
- Games
    - Automated memory matching game
- Engineering demo
    - Demo of existing project
- Souvenir factories
    - Penny-press, but for business cards
- Clocks
    - Forced perspective clock

Appendix C: Concept Refinement

Below are our pro-con lists for our concept refinement phase. These were the top 5 designs, and we aimed to objectively compare the advantages and disadvantages of each.

Table C.1. Option 1: "Block M Links"

Pros	Cons
• Interactive • Can be integrated with info • Interchangeable parts	• Not viewable from wide angles • Lots of static time • Controls-heavy • Lots of parts • More wiring • No obvious lighting integration

Table C.2. Option 2: "Forced Perspective M"

Pros	Cons
• Eye-catching • Elegant & mesmerizing • Upon further inspection, DOES feel super ME-ey • Few parts, for easy assembly	• Not interactive • Difficult to fabricate • At first glance doesn't feel super ME-ey • Potential for catastrophic failure • Potential tippy-ness

Table C.3. Option 3: "Flowering Information"

Pros	Cons
• ME 450 Information • Cool design • ME focused	• Not physically interactive • Difficult to fabricate • Potential for catastrophic failure • Would need to be very large to be read • Accessibility issues with moving text • Difficult to service • Difficult packaging geometry

Table C.4. Option 4: "Kinematic Maze"

Pros	Cons
• ME focused • Physically interactive • Cool to play with	• Potential for catastrophic failure • Difficult to make work • Would need to be very large • Difficult to service • Many moving parts • Difficult controls

Table C.5. Option 5: "Abstract Art"

Pros	**Cons**
• ME focused • Niche display • Unique art designs	• Potential for catastrophic failure • Difficult to make work • Difficult to service • Many moving parts • Difficult controls • Difficult wiring • Requires too many motors • Generic

Appendix D: Bill Of Materials

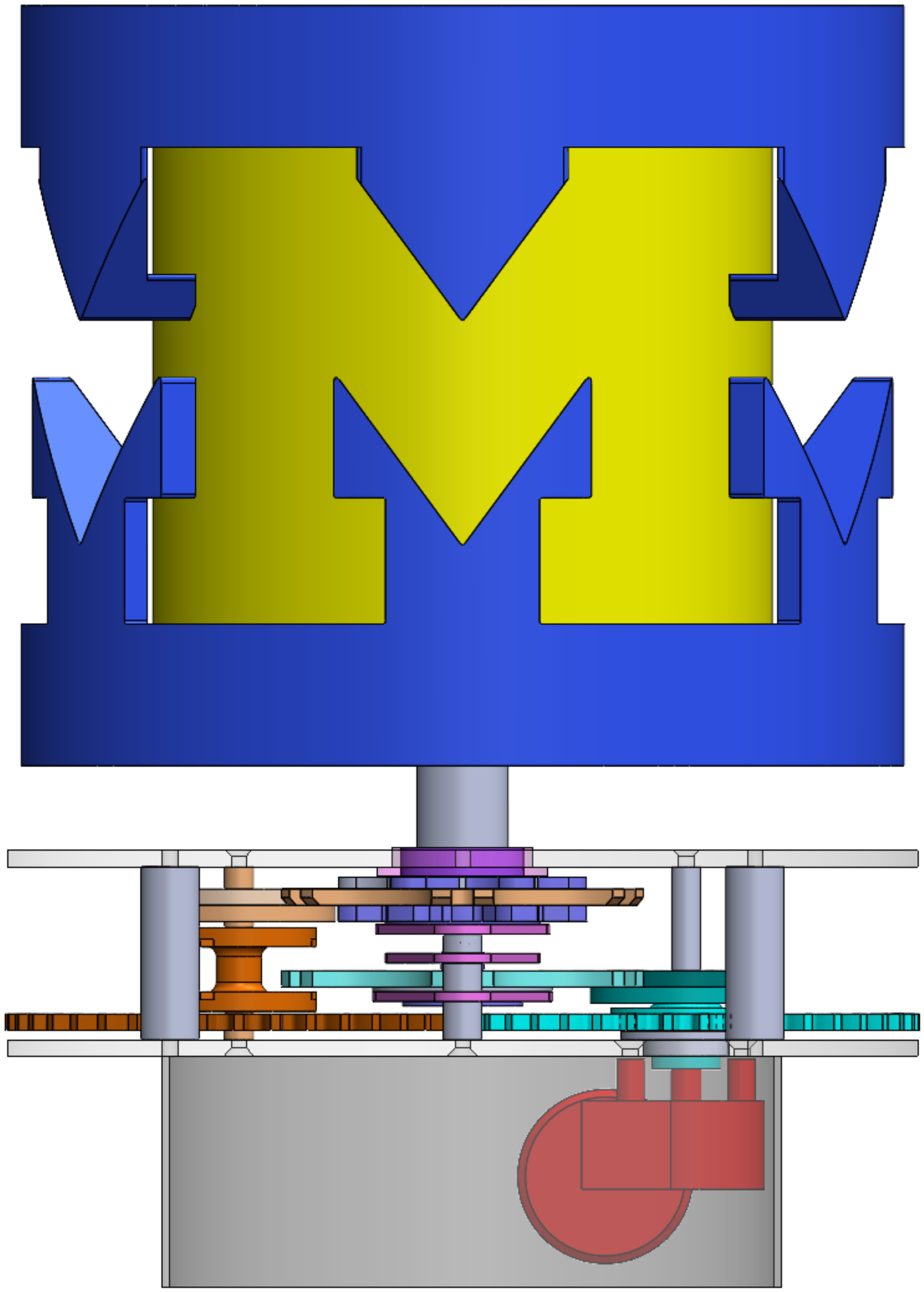
Table D1: Bill of Materials.

Item	PN	Manuf.	Vendor	Material	Qty	Total Cost
24V Brushless DC Motor, Power Supply, Potentiometer, Fwd/Rev/Off Switch	PN00220PS	Makermotor	Amazon	NA	1	**$149.00**
cncarbonfiber 2pcs 30mm Carbon Fiber Tube 30mmx27mmx500mm	-	Blackcarbon	Amazon	CARBON FIBER	1	**$39.95**
5mmx400mm Steel Dowel, Linear Motion Shaft	-	McMaster	McMaster	STEEL	1	**$20.77**
24V LED Ultrawhite Strip Light (16.4 ft long, 8mm wide)	-	Capetronix	Amazon	NA	1	**$16.99**
Electrical Slip Ring Rotary Electrical Contact	-	Taidacent	Amazon	NA	1	**$19.92**
Polycarbonate Rigid Round Tube, Clear, 7-3/4" ID x 8" OD x 12" L	PC455_L12V1	Plastic-Craft Products	Amazon	POLYCARB	1	**$60.00**
Privacy Window Film Frosted	Niviy	f-1941	Amazon	VINYL	1	**$9.99**
Tint Vinyl Film (Golden) - 12 X 48 Inches Self Adhesive	DIYAH	-	Amazon	VINYL	1	**$6.99**
Traveler's Choice Maxporter II 30" Hardside Spinner Trunk Luggage, Expandable, Navy	TC09040N30-A	Traveler's Choice	Amazon	POLYCARB	1	**$259.99**
Packing Foam Sheets, 1.5 Inch Polyurethane Cushioning	SKPTC	Juvo Plus	Amazon	POLYURETHANE	1	**$46.99**
Total for purchased components					**10**	**$630.62**
TOP M	-	3D PRINT	IN-HOUSE	PLA	1	$10.50
BOTTOM M	-	3D PRINT	IN-HOUSE	PLA	1	$11.50
TOP FITTING	-	3D PRINT	IN-HOUSE	PET-G	1	$2.12
BOTTOM FITTING	-	3D PRINT	IN-HOUSE	PET-G	1	$2.34
LIGHTING STRUCTURE	-	3D PRINT	IN-HOUSE	PET-G	1	$1.80
LIGHTING TUBE	-	BANDSAW	IN-HOUSE	PVC PIPE	1	$4.00
TALL GENEVA SPACER						$2.75
UPPER GENEVA COUPLER						$2.25
UPPER GENEVA MOUNT						$2.20
LOWER GENEVA COUPLER						$1.80
CORNER CAP BRACKET	-	3D PRINT	IN-HOUSE	PET-G	4	$6.65
CORNER MIDDLE BRACKET	-	3D PRINT	IN-HOUSE	PET-G	4	$10.50
END BOTTOM BRACKET	-	3D PRINT	IN-HOUSE	PET-G	2	$2.50
END CAP BRACKET	-	3D PRINT	IN-HOUSE	PET-G	4	$6.65
LIGHT BEARING	-	3D PRINT	IN-HOUSE	PET-G	1	$1.50
TOP CAM	-	LASER CUT	IN-HOUSE	0.25INCH ACRYLIC	2	$4.70
TOP GENEVA WHEEL	-	LASER CUT	IN-HOUSE	0.25INCH ACRYLIC	1	$5.30
BOTTOM GENEVA WHEEL	-	LASER CUT	IN-HOUSE	0.25INCH ACRYLIC	1	$5.30
COUPLER GEAR	-	LASER CUT	IN-HOUSE	0.25INCH ACRYLIC	1	$6.25
MOTOR GEAR	-	LASER CUT	IN-HOUSE	0.25INCH ACRYLIC	1	$6.25
TOP BASEPLATE	-	LASER CUT	IN-HOUSE	0.25INCH ACRYLIC	1	$12.00
LOWER BASEPLATE	-	LASER CUT	IN-HOUSE	0.25INCH ACRYLIC	1	$12.00

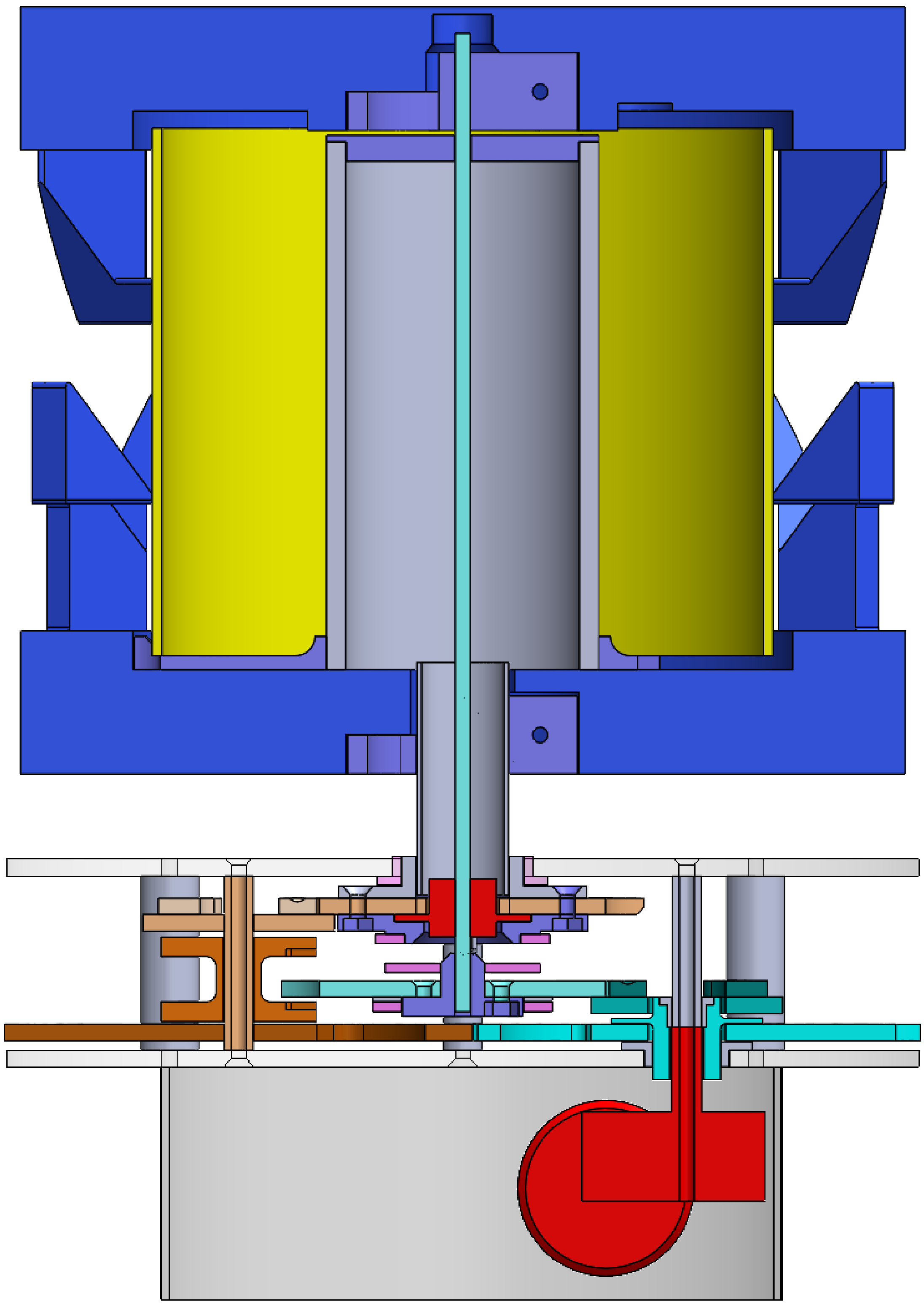
STRUCTURE PLATE - LOWER	-	LASER CUT	IN-HOUSE	0.13INCH ACRYLIC	1	$1.25
STRUCTURE PLATE - MIDDLE	-	LASER CUT	IN-HOUSE	0.13INCH ACRYLIC	1	$1.10
STRUCTURE PLATE - UPPER	-	LASER CUT	IN-HOUSE	0.13INCH ACRYLIC	1	$1.10
STRUCTURAL SPACER	-	LATHE	IN-HOUSE	ALUMINUM	4	$10.40
SHORT AXLE	-	LATHE	IN-HOUSE	ALUMINUM	1	$1.50
LONG AXLE	-	LATHE	IN-HOUSE	ALUMINUM	1	$2.10
MOTOR BEARING	-	LATHE	IN-HOUSE	POM	1	$1.20
STRUCTURAL BEARING	-	LATHE	IN-HOUSE	POM	1	$2.10
AXLE BEARING	-	LATHE	IN-HOUSE	POM	1	$1.40
STANDARD BACKDROP PANEL	-	CRAFT KNIFE	IN-HOUSE	FOAMBOARD	6	$29.98
BOTTOM BACKDROP PANEL	-	CRAFT KNIFE	IN-HOUSE	FOAMBOARD	3	$14.99
POSTER 1A	-	PRINTED	IN-HOUSE	PAPER	1	$5.25
POSTER 1B	-	PRINTED	IN-HOUSE	PAPER	1	$5.25
POSTER 2A	-	PRINTED	IN-HOUSE	PAPER	1	$5.25
POSTER 2B	-	PRINTED	IN-HOUSE	PAPER	1	$5.25
POSTER 3A	-	PRINTED	IN-HOUSE	PAPER	1	$5.25
POSTER 3B	-	PRINTED	IN-HOUSE	PAPER	1	$5.25
POSTER C	-	PRINTED	IN-HOUSE	PAPER	3	$15.75
Total for all components					**69**	**$892.85**

Note: Material cost considered for in-house components

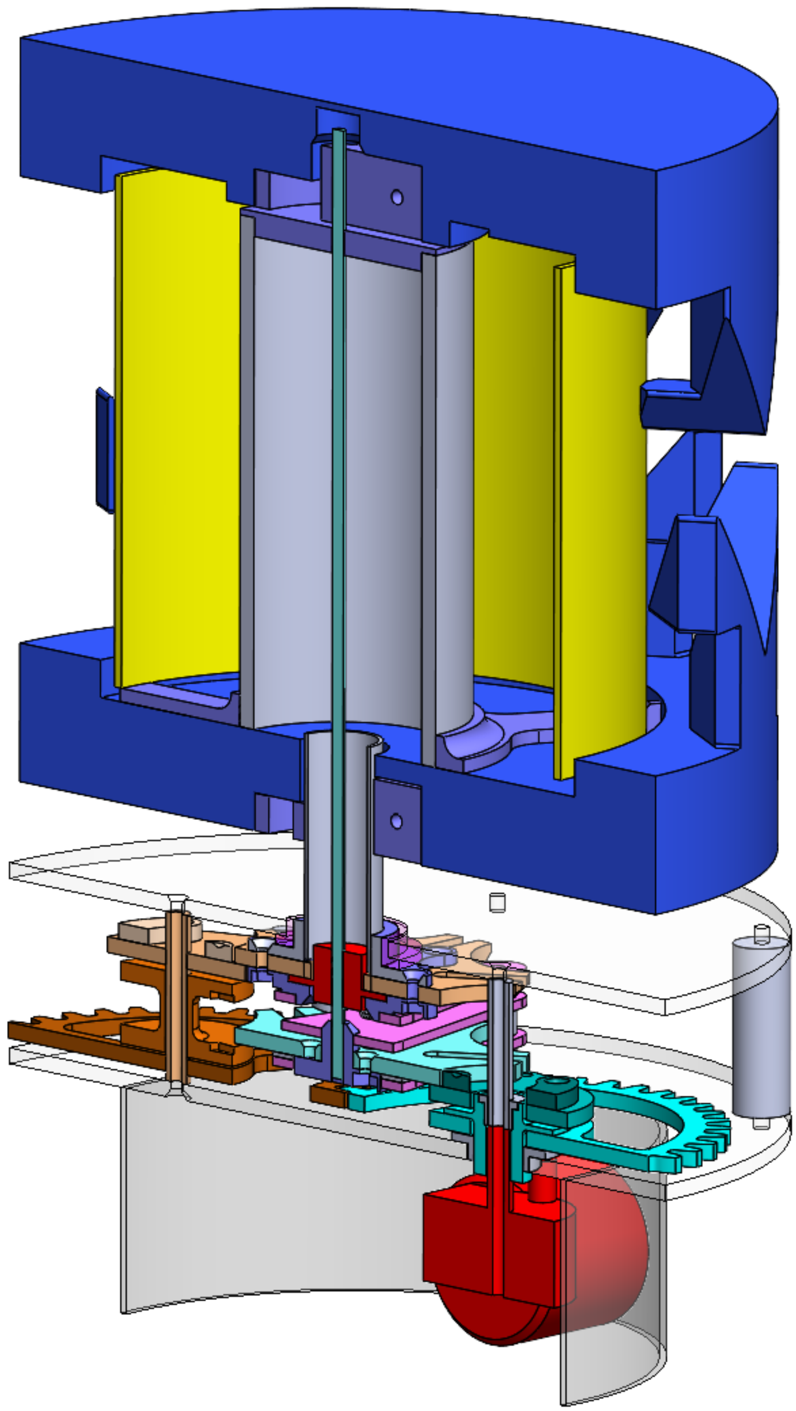
Appendix E: CAD Views & Labeled Diagrams



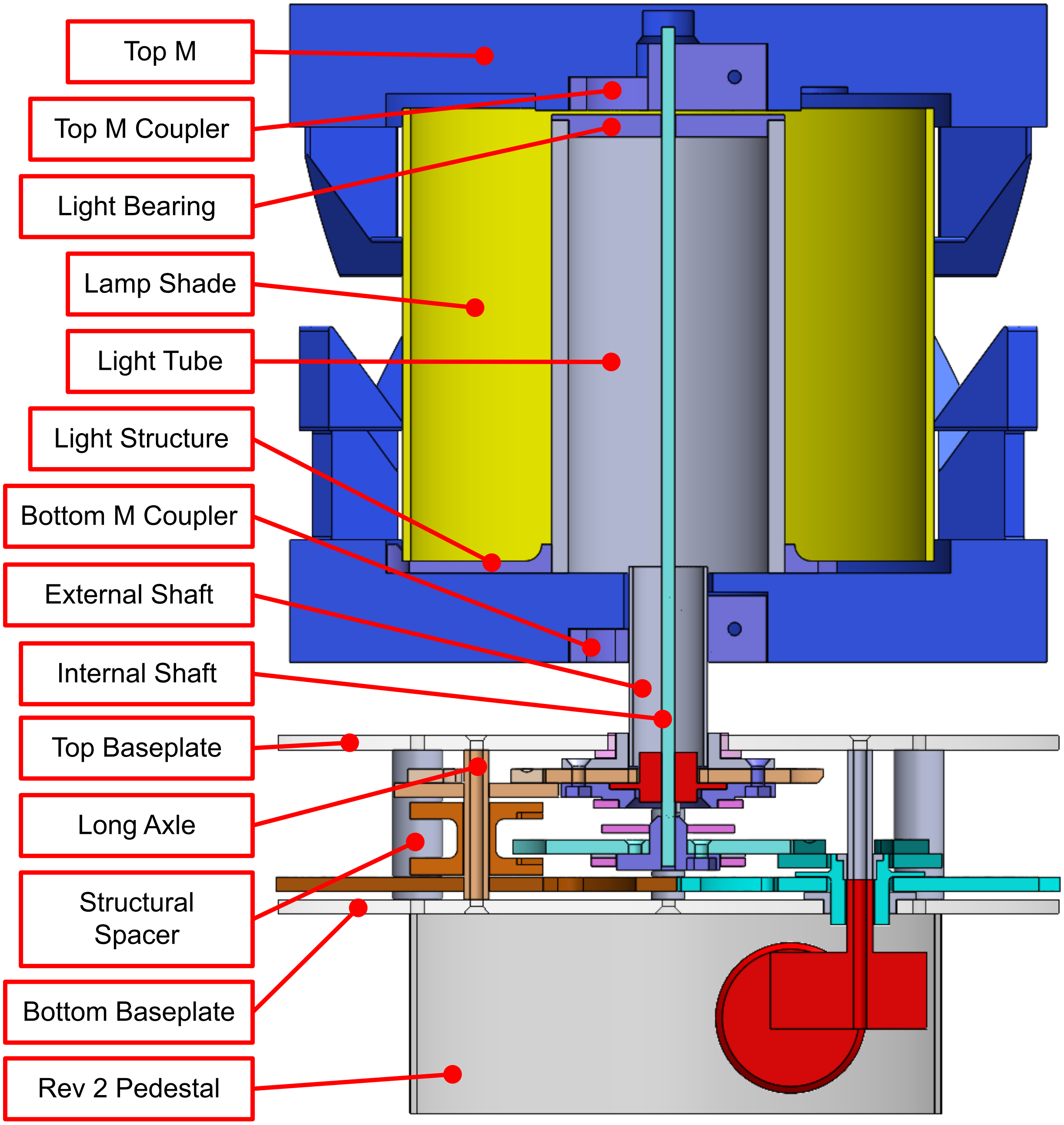
The Beacon Final CAD, Front View



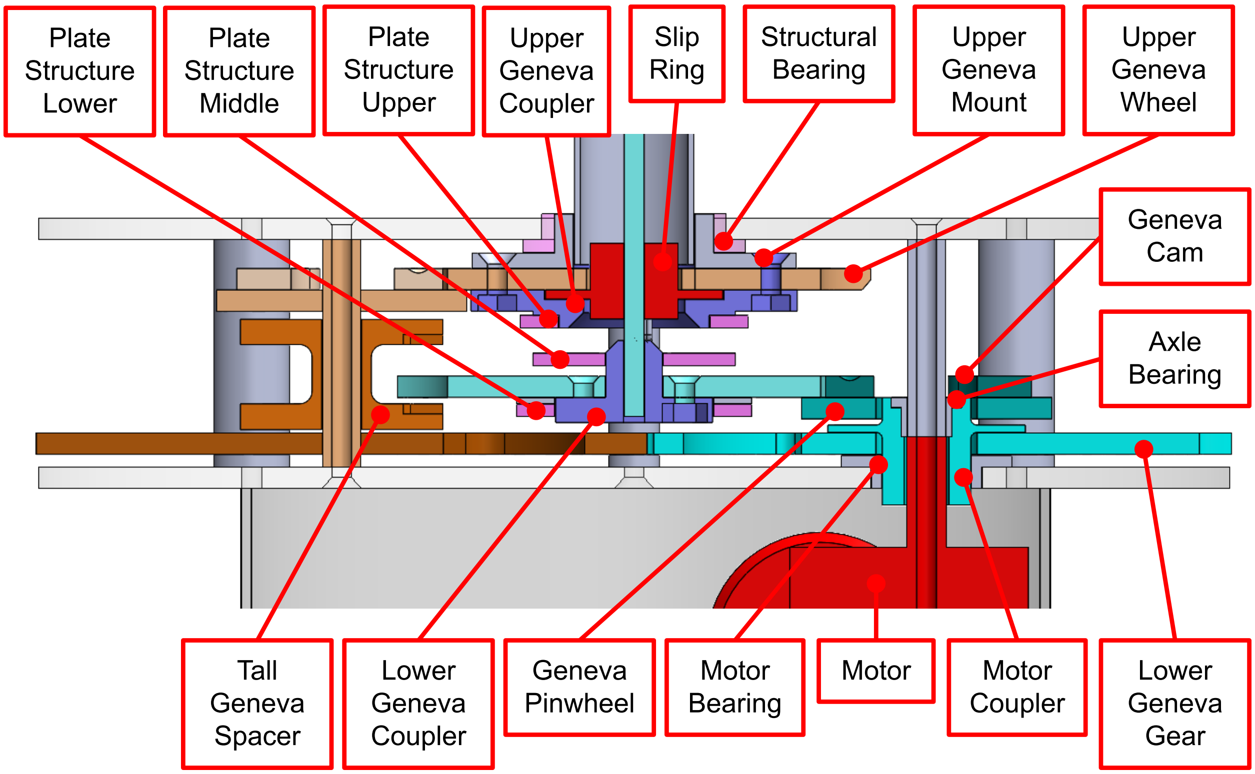
The Beacon Final CAD, Front Section View



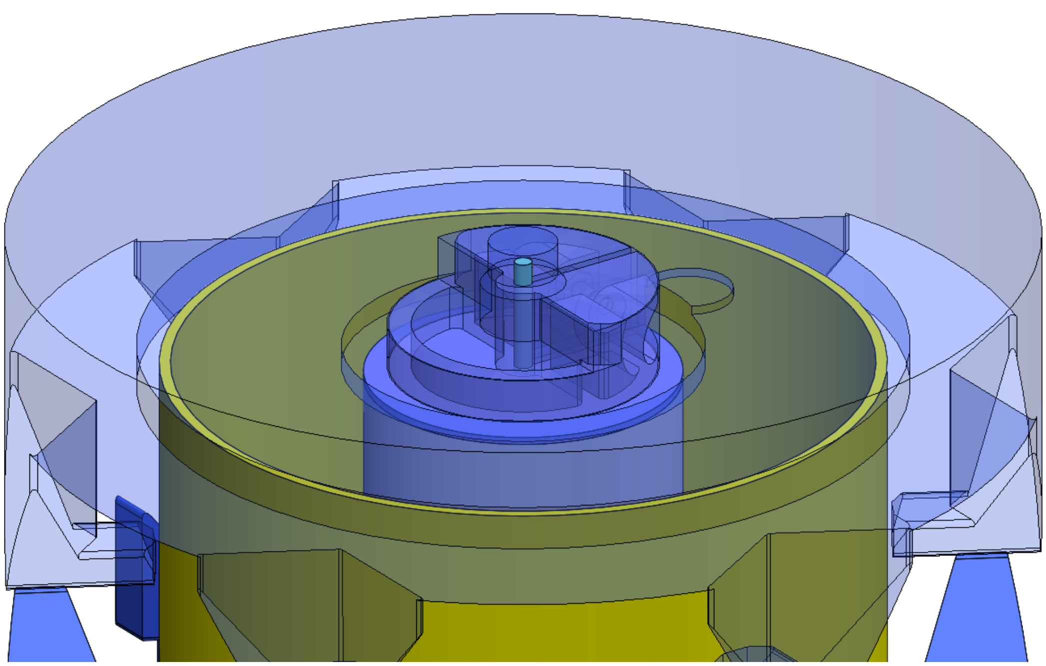
The Beacon Final CAD, Isometric Section View



The Beacon Final CAD, Front Section View, Labeled



The Beacon Final CAD, Front Section View, Mechanism Focus, Labeled



The Beacon Final CAD, Isometric View, Top Coupler Focus

Note: 10-32 fastening hardware omitted from CAD images for clarity

Appendix F: Informational Backdrop Panels

What we do

Proposal Deadline

August 1
For Fall projects (Sept–Dec)

December 1
For Winter projects (Jan–Apr)

Contact Eliza Austic

Website
me450.engin.umich.edu/contact

Email
mecheng450@umich.edu

Phone
(734) 615-8581

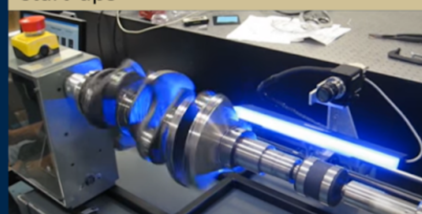
QR Code
Website Link

How Michigan ME can work with you

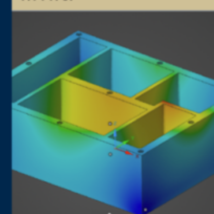
- Free project consultation
- Flexibility of involvement
- Recruiting opportunities
- Wide range of capabilities

Paraplegic Bike
Community impact

Automated Inspection Device
Precision instrumentation for start-ups



NASA Packaging
The sky is *not* the limit!



Rubik's Cube
Large-scale projects

Inverted Pendulum
Intricate designs


How we do it
Process-driven design by collegiate teams
Concept exploration
Solution development
Technical analysis
Prototype fabrication
Initial Concept
WEEK 4
Concept Refinement
Header
Left Sightline
Right Sightline
WEEK 6
Detailed Design
WEEK 8
Idea Generation
WEEK 2
Scale Prototype
WEEK 10

Appendix G: Manufacturing Plan

The Beacon

- Acrylic components
    - Acrylic components should be laser cut by taking the dxf files to the machine shop. Ensure the correct thickness is in accordance with the bill of materials in Appendix D.
- Aluminum and POM spacers
    - These should be cut to size using a lathe in the machine shop.
- 3D Printed components
    - These should be 3D printed on FDM 3D printers using PLA or PET-G. Some sanding and finishing may need to be done afterwards in order to get the components to interact correctly.
- M Halves
    - Sand the outer surface of both 3D printed block “M” halves with a hand sander. 100 grit, 200 grit, and 1000 grit sandpaper were used but adding more increments of sandpaper may be helpful. Be careful not to go too low in grit as it may damage the prints.
    - Tape off shaft connections/mates then apply two coats of Rust-Oleum 2x Ultra Cover Flat Gray Primer, two coats of Rust-Oleum 2x Ultra Cover Blue Paint+Primer, and two light coats of Rust-Oleum 2x Ultra Cover Matte Clear following the directions on the cans.
- Lampshade
    - To cut the polycarbonate tube to size, a horizontal bandsaw should be used. We laser cut two circle fittings in order for the tube to retain its shape when being clamped in the band saw vice.
    - To apply the maize tint to the outside of the polycarbonate tube, spray either the tube or the tint with soapy water and apply slight pressure during application. Bubbles will need to be pressed out as you wrap.
    - To apply the diffuser film on the inside of the polycarbonate tube, line the film and tape in place.

Informational Backdrop

- (For all informational backdrop instructions, direction such as left, right, top, and bottom are from the perspective of a viewer of the display. Panel 1 is the left wing, Panel 2 is in the middle, and Panel 3 is the right wing; Panel A is the top row, Panel B is the middle row, and Panel C is the bottom row. This nomenclature is demonstrated in Figure G.1.)

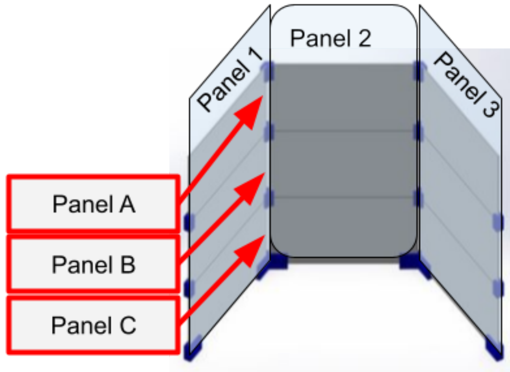


Figure G.1. An illustration of the nomenclature used for the informational backdrop panels.

- Using craft knife, cut ⅜” foamboard into 6 Panels (A and B) of 24” x 15” and 3 Panels (C) of 24” x 10.”
- Print the posters to the same respective dimensions, and cut away margins if necessary.
- 3D print 4 Corner Cap Brackets, 2 End Bottom Brackets, 4 Corner Middle Brackets, and 4 End Cap Brackets.
- Use rubber cement to adhere the posters to their respective panels at each corner (making sure the posters are aligned and smooth, and that the rubber cement does not squeeze out from under them).
- Using glue, adhere a Corner Cap Bracket to the bottom left corner, an End Bottom Bracket to the bottom right corner, and an End Cap Bracket to the top right corner of Panel 3C; a Corner Cap Bracket to the bottom left corner and a Corner Middle Bracket to the top right corner of Panel 2C; an End Bottom Bracket to the bottom left corner, a Corner Middle Bracket to the top right corner, and an End Cap Bracket to the top left corner of Panel 1C; an End Cap Bracket to the top right corner of Panel 3B (making sure to allow <1” of overhand off the top); a Corner Middle Bracket to the top right corner of Panel 2B; a Corner Middle Bracket to the top right corner and an End Cap Bracket to the top left corner (marking sure to allow <1” of overhang off the top) of Panel 1B; a Corner Cap Bracket to the top right corner of Panel 2A; and a Corner Cap Bracket to the top right corner of Panel 1A (making sure to only put glue on the back side of the foamboard).

Appendix H: Assembly Manual

The Beacon, initial assembly steps

1. Assemble subassemblies
    a. Bottom M subassembly
        i. Apply double stick tape to light tube
        ii. Wrap LED's around light tube at ½in pitch interval
        iii. Press light structure into Bottom M
        iv. Press light tube into light structure
    b. Bolt together top geneva wheel stack
        i. Top Geneva Mount
        ii. Top Geneva Wheel
        iii. Slip Ring
        iv. Top Geneva Coupler
        v. 10-32 bolt/nut - 3x
    c. Bolt together bottom geneva wheel stack
        i. Bottom Geneva Mount
        ii. Bottom Geneva Wheel
        iii. Bottom Geneva Coupler
        iv. 10-32 bolt/nut -3x
    d. Bolt together tall gear stack
        i. Geneva Cam
        ii. Geneva Pinwheel
        iii. Geneva Pin
        iv. Tall Geneva Spacer
        v. Tall Geneva Gear
        vi. 10-32 bolt/nut - 6x
    e. Bolt together short gear stack
        i. Geneva Cam
        ii. Geneva Pinwheel
        iii. Geneva Pin
        iv. Motor Coupler
        v. Short Geneva Gear
        vi. 10-32 bolt/nut - 3x
        vii. Press in coupler bearing
    f. Bolt together internal axle
        i. Top-M Coupler
        ii. Long Axle
        iii. Slide light bearing onto axle
        iv. 10-32 bolt/nut
    g. Bolt together external axle

    i. Bottom-M coupler
    ii. Short axle
    iii. 10-32 bolt/nut
  h. Assemble Top Baseplate Sub
    i. Acquire Top Baseplate
    ii. Press in Structural bearing
    iii. Bolt in short axle (10-32 nut/bolt)
    iv. Bolt in long axle (10-32 nut/bolt)
2. Assemble structural spacers to bottom baseplate
3. Bolt motor to bottom baseplate
4. Press short gear stack onto motor shaft
5. Slide tall gear stack onto long axle
6. Construct geneva wheel structure
  a. Slide bolts into bottom baseplate
  b. Slide spacers onto bolts
  c. Slide Structure Plate - lower onto bolts
  d. Press geneva bearing into structure plate
  e. Slide lower geneva wheel stack subassembly into geneva bearing
  f. Slide spacers onto bolts
  g. Slide Structure Plate - middle onto bolts
  h. Slide spacers onto bolts
  i. Slide upper geneva wheel subassembly onto bolts
7. Bolt upper baseplate sub onto existing assembly

The Beacon, assembly steps for trade shows

1. Place lower gearbox onto table
2. Insert external axle subassembly into upper geneva wheel
3. Slide Bottom-M subassembly onto bottom-coupler
4. Connect lighting connectors
5. Slide internal axle assembly into light tube and bottom geneva wheel
6. Place lamp shade into lighting structure
7. Slide Top-M onto top-coupler
8. Plug two power supplies into wall
9. Adjust knobs to preferred LED brightness and motor speed

   (Reverse directions for disassembly)

Informational Backdrop

(For all informational backdrop instructions, direction such as left, right, top, and bottom are from the perspective of a viewer of the display. Panel 1 is the left wing, Panel 2 is in the middle, and Panel 3 is the right wing; Panel A is the top row, Panel B is the middle row, and Panel C is the bottom row. This nomenclature is demonstrated in Figure H.1.)

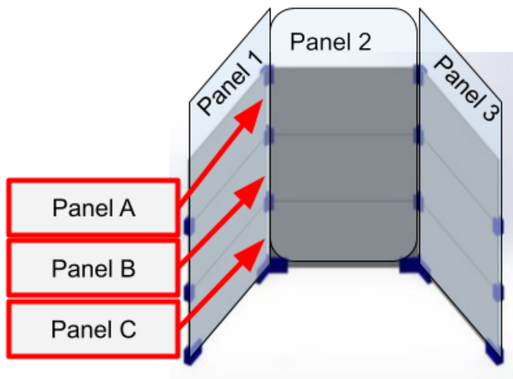


Figure H.1. An illustration of the nomenclature used for the informational backdrop panels.

1. Place Panel 3C on the table.
2. Slot Panel 2C on to the left side of Panel 3C..
3. Slot Panel 1C on to the left side of Panel 2C.
4. Slot Panel 3B on to the top of Panel 3C.
5. Slot Panel 2B on to the top of Panel 2C and the left side of Panel 3B.
6. Slot Panel 1B on to the top of Panel 1C and the left side of Panel 2B.
7. Slot Panel 3A on to the top of Panel 3B.
8. Slot Panel 2A on to the top of Panel 2B and the left side of Panel 3A.
9. Slot Panel 1A on to the top of Panel 1B and the left side of Panel 2A.

(Reverse directions for disassembly)

Appendix I: Design Expo Pictures


COLLEGE OF ENGINEERING
MECHANICAL ENGINEERING
UNIVERSITY OF MICHIGAN
Who we are
Capstone Design Program
Benchmark university course
Senior undergraduate experience
Solving real, complex problems
Industry-sponsored projects
Fall or Winter semester
MAKING THE WORLD WORK BETTER
State-of-the-art facilities
In-house machining & 3D-printing
Cutting-edge research
Experienced, world-class faculty
University of Michigan
Founded 1817
Dozens of yearly startup launches
$1.71 billion in research
Mechanical Engineering
Est. 1868
$42 million in research
Top-10 program nationally
College of Engineering
What we do
Proposal Deadline
August 1
For Fall projects (Sept-Dec)
December 1
For Winter projects (Jan-Apr)
Contact Eliza Austic
Website
me450.engin.umich.edu/contact
Email
mecheng450@umich.edu
Phone
(734) 615-8581
How Michigan ME can work with you
Paraplegic Bike
Community impact
Automated Inspection Device
Precision instrumentation for start-ups
Rubik's Cube
Large-scale projects


What we do
Contact Eliza Austic
Website
me450.engin.umich.edu/contact
Email
mecheng450@umich.edu
Phone
(734) 615-8581
QR Code
Website Link
Michigan ME
work with you
Free project consultation
Flexibility of involvement
Recruiting opportunities
Wide range of capabilities
Automated Inspection Device
Precision instrumentation for start-ups
NASA Packaging
The sky is not the limit!
Inverted Pendulum
Intricate designs
How we do it
Process-driven design
by collegiate teams
Concept exploration
Solution development
Technical analysis
Prototype fabrication
Initial Concept
Concept Refinement
Detailed Design
Idea Generation
Scale Prototype
WEEK 4
WEEK 6
WEEK 8
WEEK 10
PROBLEM
DESIGN PROCESS, CONTEXTUAL FACTORS, AND SOCIETAL IMPACT
REQUIREMENTS AND SPECIFICATIONS