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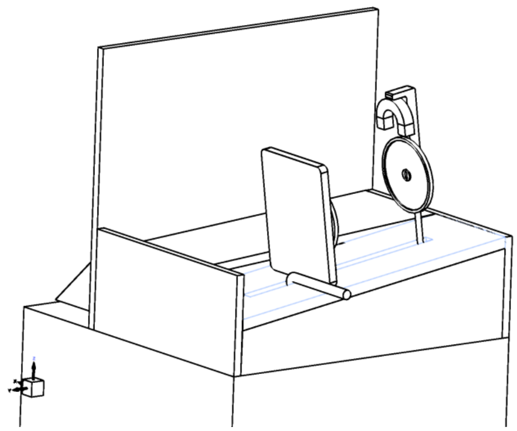


RMSC "HOW THINGS WORKS" EXHIBIT: WIRELESS CHARGING

Charlie Herman **Katie Jarvis** **Anne Traczyk** **Jennifer Yu**

ABSTRACT

Inspired by the increasing presence of modern technology in everyday life, this project was developed as part of a contemporary technology exhibit. The final concept focused on demonstrating the principles of wireless charging, making it a suitable addition to the How Things Work exhibit currently housed at the Rochester Museum & Science Center (RMSC). electricity is generated when the coils are brought closer together. In real wireless charging, this happens due to a current induced in the receiving coil. In our exhibit, an ultrasonic distance sensor is used to produce the same effect. This board then illuminates a set of lights, visually representing the wireless transfer of energy. The interaction between the two induction coils is key: when brought closer together, the magnetic field felt by the receiving coil is intensified, successfully powering the lights; when moved farther apart, the perceived field weakens, and the lights turn off. This hands-on demonstration is designed to be educational and engaging for children aged 5 to 15, as well as their guardians, helping them better understand the basic concept of wireless energy transfer.

PROBLEM DEFINITION

Adults who take children ages 5 to 15 to visit the RMSC expect the museum to teach both them and their children about science, technology, engineering, and math (STEM) concepts in the world around them in a way that is intuitive as well as engaging to both the child and adult. In a broader scheme, the education of children in these STEM concepts will help in adjusting the child for adult life and contribute to the furthering of society as a whole. One topic that few people understand is wireless charging.

REQUIREMENTS, SPECIFICATIONS, DELIVERABLES

The RMSC has outlined several key deliverables for this project, including a proof-of-concept demonstration to evaluate the feasibility of the proposed idea, a first-stage prototype, a second-stage prototype, and a final report. To initiate development, the project must include a CAD model with a bill of materials, a theory of operation manual, and preliminary design concepts. The theory of operation manual is underway.

The wireless charging system must meet several key requirements: it should attract user interest through sensory queues, be intuitive, easy to use and to understand, as well as provide an interactive experience. Additionally, it must be safe for public use, meeting ADA requirements. It should be wheelchair accessible, and feature clear, readable signage with minimal visual distractions—avoiding strobing lights or rapid movements. The coils must also power off in between uses so as not to waste electricity and become dangerously hot.

Project specifications include a footprint of either 30”×30” or 30”×60” and a maximum height of 7 feet. To ensure wheelchair accessibility, the tabletop must be close to 27” high (± 6”), and all text must be in a sans-serif, 24-point font or larger. The LEDs require a minimum of 8 volts to illuminate and will need an amplifier. The LED strip must be at least 1 meter long and individually addressable in order to discretely vary illumination as voltage increases. The circuit must include a rectifier to convert AC to DC current in order to power the LEDs.

All components—including the poles, coils, and model phone—must remain entirely within the 30”×30”×7’ design envelope. The model phone will be 18 inches long, 10 inches high, and less than 3 inches thick. The interactives must also not require more than 5 lb_f to use, as required by ADA specifications.

CONCEPTS

Concept 1: Baseline (Fig. 1 in Annex A)

This first concept uses a flat platform, with the phone being movable horizontally closer and farther away from the wireless charger. The charger is fixed and held upright. The phone, made from clear plastic to display the coil inside, is movable on a drawer slider via handle sticking out from the side of the phone. The charger is attached to the wall and a transformer which steps down the voltage to a safe level. The coiled wire on the phone is surrounded by LED lights hooked to an amplifier and Arduino. The Arduino senses the amplified voltage, converts it to DC current, and outputs a signal to turn on different lights depending on the induced voltage. This idea would require some sort of electronic system for power shutoff after a given time interval.

Concept 2: Vertical (Fig. 2 in Annex A)

In the second concept, the whole system is rotated such that the tracks are vertical. In this case, the charger is lifted to the phone. As the charger is moved closer, the phone screen turns on and displays an explanation of wireless charging.

Concept 3: Inclined (Fig. 3 in Annex A)

The third concept is nearly identical to the first, the key difference being the inclination of the table. This incline means that the phone must be moved and held by the user to activate the charger. When released, it will slowly roll back down, halting induction.

Pugh Matrix Criteria: (Pugh Matrix in Appendix)

Ease of use – How difficult is it to physically operate the mechanism? This is mainly dictated by force required to push the coil back and forth. (a (-) occurs only if the design is significantly harder to operate)

Intuitive use – How closely does the model mirror real life?

Ease of Manufacture – How complicated/intricate are the components. This may be dictated by bracing required, electrical components?

Safety – What is the likelihood of danger due to pinch points, overheating wires, or electrocution? Safer designs are favored.

The final design chosen was the inclined configuration. Through our statics equations (Fig. 8 in Annex A), we found that none of the designs were significantly more difficult to use based on applied force alone (0 lb_f, 0.804 lb_f, 0.266 lb_f, respectively). Safety was also an important factor. The inclined design greatly reduces the chance that coils will be left connected for an extended period of time. The vertical exhibit also runs the risk of people using it wrong. In real life, people put their phones on their charging pads, not the other way around. Too much force on the stationary piece (the phone) could lead to breakage and wear that can be avoided with the other two designs. The LEDs are not included as the power requirements on those will be supplied by an external power source, which will be activated by the Arduino.

Throughout the project slight variations of the front face for the inclined model were used and tested at the RMSC museum. The initial inclined model was viewed so that the user could see the distance of the coils and slide the moving coils from right to left. Then the slightly modified model was to have the front of the model be the original side view so that the user had to push from front to back. As this version was being tested, it was observed that the users had trouble seeing the distance of the coils. To react to this issue, the design was changed back to sliding the coils from right to left. This change improved the ease of viewing what was happening and helped connect the concept of how wireless charging works. Therefore, reverting to the original view of sliding the coils from left to right became the final design.

MECHANICAL ANALYSIS

Tolerance Analysis:

One tolerance-related issue our team encountered involved creating the 0.845” diameter hole in both base stands. The hole on the moving base stand was slightly oversized, requiring additional PVC glue to fill the gap. This not only increased the curing time but also reduced the structural tightness of the fit. Conversely, the hole in the stationary base was extremely snug and required significant force to insert the stand with the PVC glue. Despite both holes being measured with a tolerance of ±0.02 inches, the actual fits varied noticeably. The tolerance analysis calculations can be seen in Fig. 5. The final calculated range that the pole could fit through without any major issues ended up being a minimum diameter of 0.8248” and a maximum diameter of 0.8648”.

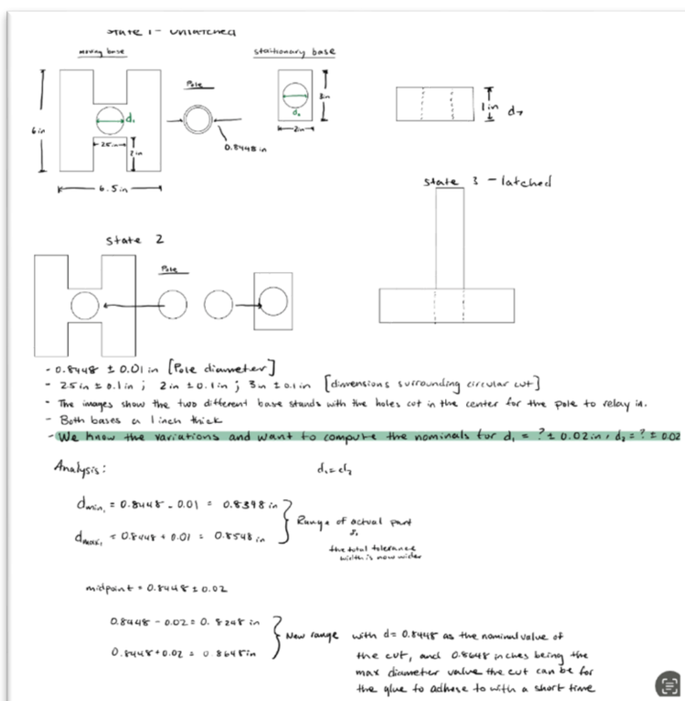


Figure 5: Tolerance Analysis

There were other aspects of the project which related to tolerance analysis, such as the drilling of the slots and wire holes in the acrylic disks, but for the most part, these were accomplished by measuring the diameter of the bolt or wire in question, locating the corresponding drill bit, and moving up a size or two.

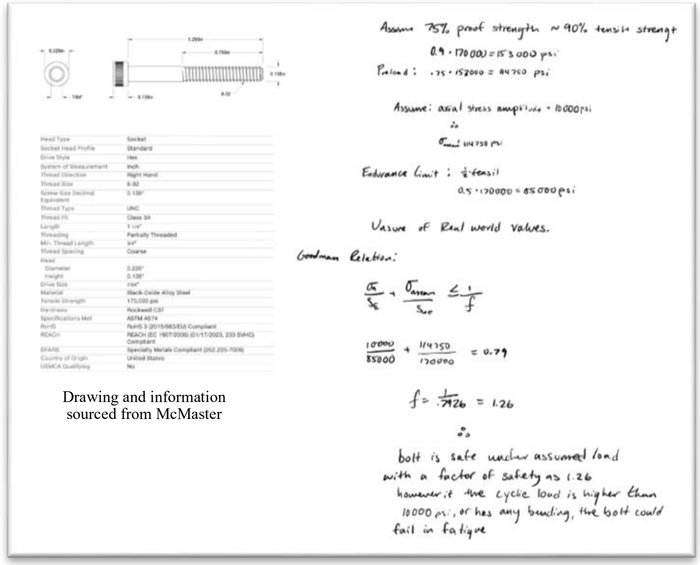
Mechanical Fatigue Analysis:

One aspect of fatigue analysis our team considered was the number of times a user could operate the exhibit before the drawer slides beneath the wooden bed surface will begin to degrade and no longer slide smoothly. The fatigue analysis will be on the stainless-steel component with the use of dynamic movement. When designing and analyzing the drawer slides, it is important to consider that they must necessarily withstand greater forces when in motion compared to when stationary. Dynamic loads significantly impact both the life expectancy and performance of a slide. Several load factors further influence slide performance, including the distribution of the load and its degree of centering. The position of the load's center of gravity relative to the slide's centerline of travel plays a critical role. Additionally, the number of cycles, the rate and frequency of operation, the length of each cycle stroke, the percentage of total slide travel used, and the stopping force and distance all contribute to overall wear and stress on the slide. Understanding these factors is crucial for ensuring reliable and efficient slide operation under dynamic conditions.

Stainless steel exhibits a 'fatigue limit' or 'endurance limit' during cyclic stressing. This means that there is a stress level, below which fatigue failure should not occur. This is determined from a series of fatigue tests, run to failure at various stress levels. The fatigue stress limit is reached when failure does not occur after a million, (10^6), or 10 million, (10^7), cycles.

As lifespan was not a project requirement for this second-stage prototype, a fatigue analysis was not conducted. However, if the museum decides to move forward with this exhibit, a lifespan analysis would likely be beneficial when considering the suitability of the drawer slide hardware.

The computational analysis was done on the 6-32 1-1/4" long partially threaded Black Oxide Alloy Steel Bolt that we used to hold together our bases to the drawer slides. The analysis is attached below by assuming 75% proof strength for adjustable screws and a 10,000 cycle load.



Drawing and information sourced from McMaster

Figure 6: Fatigue Analysis

Fastener Torque Calculations:

To attach the moving coil to the base, the PVC board referenced in the tolerance analysis section was attached to the metal drawer sliders. Since these are meant to be disassembled at will, the force required to fasten the PVC and the steel together is 0.75x the preload.

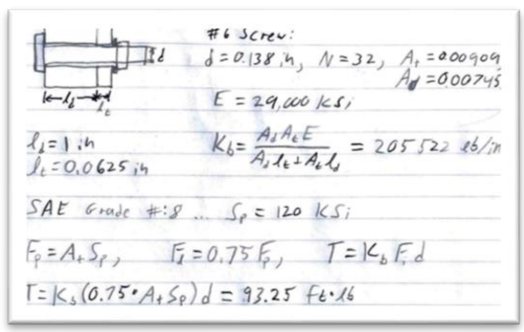


Figure 7: Torque Analysis Calculation

In this analysis, a 6-32 screw made from a medium carbon alloy (SAE Grade #8) was used. The PVC is 1 inch thick, and the steel drawer sliders-the other member-is 1/16 inches thick. Under these conditions, the proper torque required is around 9.3 ft·lbs.

The analysis is calculated assuming the steel bolt is fastened onto a steel base material. This analysis can not be assumed safe or long lasting with a steel bolt fastening a PVC material.

Materials Selection Analysis:

PVC was selected as the material for the base stands on both the stationary and moving sides due to its lightweight nature and ability to provide a secure attachment to the base. Using alternative materials would have significantly increased costs. Additionally, the PVC was available on short notice and matched the required wall thickness to ensure the pipe would remain secure during user interaction.

Polycarbonate was chosen for the coil disks due to its transparency and ease of machinability. The exhibit is designed to promote learning. Allowing guests to view the coils from any angle provides more visual information to foster curiosity.

The 18-guage copper wire was chosen to be easily visible while also generating a safe and sufficient amount of power to operate the indicator lights monitored through the Arduino. Although it was eventually decided against connecting the receiving coil to the Arduino, it was decided that leaving the museum with a pair of working coils was important for future exhibit development. Solid-core wire was chosen over stranded for the coils as it is more effective at generating a magnetic field. However, directly before exiting the rigid polycarbonate coil disk, the wire is transitioned to stranded machine wire, which is more flexible and better suited for moving components.

Plywood was used for both the base and the phone model due to its low cost, ease of manufacture into various shapes and sizes, and versatility in finishing. Given that the final model required visually appealing features, wood was ideal as it could be easily primed and painted in any desired color.

Structural Finite Element Analysis:

The magnet interactive piece of the exhibit can be structurally tested. Since there will be a string that holds the magnet in place through the part, a structural FEA can be done on the piece that holds the magnet up. This analysis will show how the amount of deformation the part has when the weight of the magnet is being held up which is estimated as about 0.5 lb (the approximate weight of the magnet) applied at the top hole in the -Z direction. The 4 holes on the base plate are a fixed constraint. The material used for the simulation was PLA. A linear static solution with a 3D tetrahedral mesh was used (CTETRA (4)). Although this simulation can be similar to a cantilever beam, the bends and corners at the top may affect the way it is simulated therefore a 3D mesh type was used instead of a 2D mesh with a beam.

This analysis also does not account for the fact that there will be a case super glued to the top to keep the string inside which will provide some stiffness to the overall part. Having this analysis with just the base part of the magnet interactive piece will show more deflection than it would actually experience which means the actual deflection of both parts would be less than what is calculated. The deformation due to this analysis is 0.0914 inches as shown in the image in figure 7.

The FEA should also be considered for an analysis on stress for the circumstance that the audience tends to push on the magnet interactive with their hands; since PLA is a brittle material this analysis would fail.

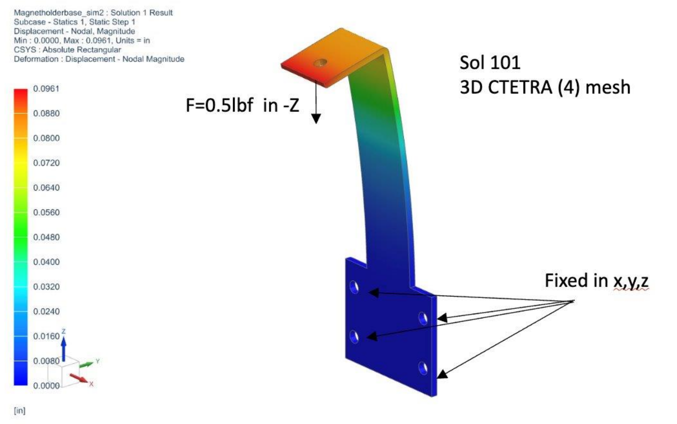


Figure 8: Deflection of magnet interactive

Fundamental Mechanical Analysis:

The ADA requirement of not requiring more than 5lb$_f$ to operate required a statics analysis. In this analysis, a set of stainless-steel drawer slides were chosen and a statics model was used to estimate the force required to overcome static friction to move the slider base.

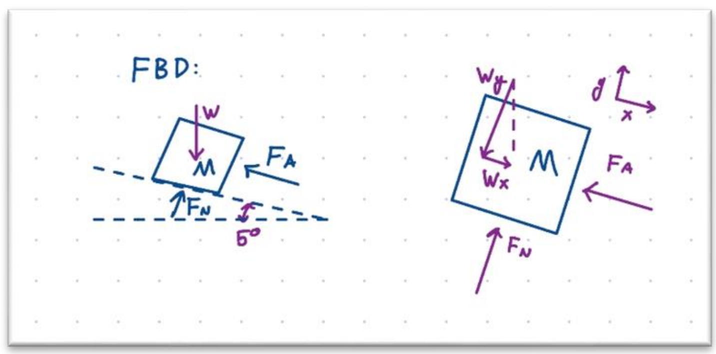


Figure 9: Statics Model of Moving Coil

In the above image, a free body diagram is included. M represents the combined mass of the non-fixed drawer sliders, coils (including wire and polycarbonate holder), the PVC pipe, and the PVC block that connects the coils and slides. Matlab was used to carry out the statics analysis and the expected force required was computed (using the MATLAB script in the annex) to be 0.4448 lb$_f$, which is less than a tenth of our required maximum. Our actual force of operation was measured to be 0.4 lb$_f$ (albeit without the coils or phone attached). The fact that this value was so low compared to our maximum allowable force allows us to have the freedom to increase the incline if desired, which might be explored in later iterations.

Magnetic Field Analysis:

One safety concern that had to be addressed regards potential electromagnetic interference (emi) between the powered coil and human users. According to the National Institute of Standards and Technology's guide on *Magnetic Field Safety* (NIST S 7101.53) [1], there is a maximum allowable magnetic flux density value of 0.5 mT for medical device wearers.

The magnetic field at various distances along the center axis of the coil was calculated using an online Magnetic Field Calculator [2] to exhibit the following relationship between field strength and distance.

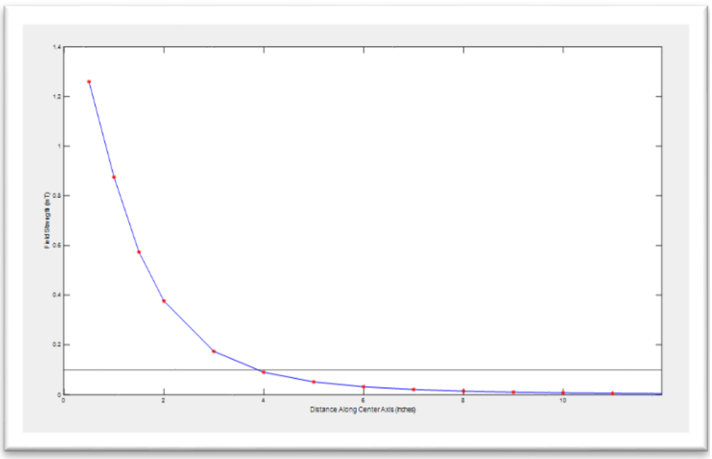


Figure 10: Graph of Magnetic Field Strength

The black line represents the maximum allowable field strength. For most medical wearables, maintaining a distance of 6 in. from any strong magnet is recommended. Thus, signage reminding users with medical devices to maintain a distance of 6 in. from the coils should be sufficient.

MANUFACTURING

The manufacturing was split into separate sections: the base, coils, and electronics. The base was made from ½ in. and ¾ in. plywood, wood screws, and wood glue. After the pieces were cut as shown in our drawing package, the two larger sides were screwed together without the front and pack panels. Then the middle piece with the slot was glued between them, resting on the front panel. After a redesign, the left side was removed and a new piece was screwed into the slotted board to seal the box. An additional two nails were used to provide extra support to the glued joint. Following assembly, the base was thoroughly sanded, primed, and painted before attaching either coil sub-structure.

The coils are made of insulated wire wrapped in a spiral around a central post. The wire was laid flat and affixed to a piece of polycarbonate using 2-part epoxy. The polycarbonate was CNC'd to the correct size and shape.

PVC board was CNC'd to act as an interface between a ½ in. PVC pipe and a set of drawer slides which were screwed to the underside of the slotted piece of the base. Once the PVC was attached at both stationary and moving ends, holes were drilled into the protruding PVC tubes to bolt the coils.

For the moving side, a 3D-printed spacer keeps the coil and the wooden phone parallel, with a notch cut into the PVC pipe to accommodate the wires, which exit through the back of the coils and travel through the tubes to the cavity inside the base.

For the stationary side, a 3D-printed post sits over the PVC tube, and the coil is bolted through the tube and affixed to the 3D-printed post using epoxy. In this side as well, the wires are fed through the tube. A fishing line travels through the post and to the bottom of the tube, where a weight is attached. At the other end of the wire, hanging in front of the coil, is a 3D-printed housing for magnets. This housing can be handled by users to explore the interactions between the magnets and the oscillating field.

The electronics were assembled according to the circuit diagram in Annex Fig 10. All the electronics are secured to the base, with an access panel on the back. All connections are soldered, with the exception of the wires which are connected using banana plugs to the output of the 6 V AC power supply.

Table 1: Prices, Materials, Quantity Chart

Material	Unit Cost	Quantity	Total
½ in. Plywood	$1.45/sq.ft.	12	$17.4
¾ in. Plywood	$1.92/sq.ft.	3	$5.79
½ in. Polycarbonate	$20.89/sq.ft.	1	$20.89
½ in. PVC board	$3.75/sq.ft.	1	$3.75
¾ in. PVC pipe	$2.60/ft.	3	$7.80
Miscellaneous wood screws	$0.13/piece	30	$3.90
Drawer sliders	$8.06/pair	1	$8.06
18 AWG wire	$0.21/ft	80	$16.80
Gorilla epoxy	$5.97/tube	.5	$2.99
PLA filament	$20/kg	.1	$2
Arduino Uno	$19.99/board	1	$19.99
Arduino ultrasonic sensor	$3.95/sensor	1	$3.95
2 ohm, 50 watt resistor	$1.86/resistor	1	$1.86
Heat sink	$13/unit	1	$13.00
Power supply	$20/unit	1	$20.22
LED strip	$19.95/strip	1	$19.95
Op-Amp	$0.38/op-amp	1	$0.38
Jumper wires	$0.08/wire	4	$0.32
Shop time	$100/hour	50	$5000
Total:	$5169.05		

If the system was to be scaled to 1000 systems, much of the cost would be cut by reducing manual manufacture requirements. Much of this could be cut by the fact that mass production can be automated or, at the very least, manufacture time is reduced when the same piece is replicated in bulk.

Additionally, smoother wood could be used to reduce the necessity for sanding, and jigs could be made to produce more accurate inclines without the need to set adjustable guides. Assuming the machined pieces are still produced using the same equipment, and everything else is similarly done by hand, by more practiced workers, the shop time could likely be reduced to around 8 hours per system.

If we choose to reimagine the manufacturing process with new equipment, we could reduce scrap and speed up machining time. Instead of cutting the polycarbonate from a sheet, columns of material could be put on a lathe. All that would need to be done would be to carve out the middle where the wires lay, drill a hole in the center, and trim the piece off, exposing a fresh face for more cutting.

Additionally, much time could be saved by improving the coil-winding process, which took about 6 hours in total for the two coils. If a rotating cylinder was used to wind the coils, and two plates were situated above and below the wire, coils could be wound much quicker and more uniformly. If these plates were covered with Teflon, gluing could also occur in this process. By combining these two steps, a finished coil could likely be made in under a minute with properly tuned machines.

Another way to decrease the cost and time would be to integrate the electronics into one system. This could be custom ordered and delivered pre-programmed and soldered. In bulk quantities, this may even be cheaper than the current Arduino setup.

While these are reasonable ways to increase output, it should be noted that museum exhibits are not mass produced, and this falls outside the scope of our project.

TEST PLAN AND RESULTS

Table 2: Test for requirements of project

Requirements	
☐ Must be attractive	☐ Safe to use
☐ Not overloading to senses	☐ Wheelchair accessible
☐ Must be intuitive to use	☐ Must be readable
☐ Must be easy to operate	☐ Must be interactive

Table 3: Test for Specifications

Specifications	**Units**	**Nominal**	**Actual**	**Passed?**
Exhibit footprint	in	Within 30” by 30”	30” by 20”	Yes
Maximum height	ft	7’	60”	Yes
Table height	inches	27”	29” (ish)	No
Minimum text size	points	24	41	Yes
Power demand (coils)	W	12	20.275	No
Force to use	lb_f	Less than 5	0.4	Yes

<u>On Requirements:</u>

Attractiveness was tested in the museum. An attractive exhibit draws attention without the need for human supervisor intervention to attract potential users. During our first round of testing, users did not approach without our coaxing.

Intuitiveness was also tested at the museum. An intuitive exhibit can be operated without verbal instructions. Most users understood that the coils must be pushed together once an arrow was drawn

Sensory Overload occurs when fonts are not clear, movements are quick, lights strobe, or audio is unclear or too loud. None of these are present in the design

Ease of Operation is not passed if users are not physically capable of operating the exhibit (due to jamming, friction, or other physical barriers). Every user, once prompted with what to do, was able to push the coils successfully.

Safety of Use is difficult to truly test with a small sample size. During testing, no user was hurt in any way, but further supervised testing is suggested to ensure that splinter or pinching injuries are not possible. By placing the only high-temperature component (the resistor) beneath the sealed base cavity, there is no risk or burn. All wires are insulated. There is no danger of electrical

Wheelchair Accessibility can be accommodated in a few ways. Either a “dock” can be included in the cabinetry which allows wheelchair users to position themselves beneath the work surface (like a desk) or a “roll up” approach can be accommodated, where users can position themselves beside the exhibit. This design currently reflects a “roll-up” design, which is achieved by the sub-27” surface height

Readability is a function of both font size and graphic design. A graphic is readable if it is not visually overstimulating, uses audience-appropriate language, and view of text is not obstructed. This

Interactivity is achieved when users are capable of manipulating the setup in front of them to elicit a sensory response. This exhibit is interactive in two ways: One interaction occurs when the user moves the two coils toward each other and the LED strips light up; the other occurs when a user uses the attached magnet to feel the alternating current in the source coil.

<u>On Specifications:</u>

Exhibit footprint is the table space used by the exhibit. The CAD design was modeled to make use of a 30” by 30” square footprint and the final design was measured with a ruler to fit within this space.

Maximum Height is the maximum allowable height of the work surface in order for the exhibit to be ADA accessible (and, as a secondary benefit, to make the exhibit easier for small children to use). Assuming the exhibit sits on a cabinet that is 20” tall, the height of the table varies from 26 to 29 inches. This is not within the specifications, so adjustments should be made prior to the design reaching the museum floor.

Minimum Text Size is the smallest point-size for the smallest body of text on the exhibit. Since the graphic was designed to-scale using Canva, the text size could be measured in the program.

Maximum Power Demand was set for safety reasons. This specification's value should likely be reexamined. As of now, this specification has not been met.

Force to use is an ADA specification requiring that no more than 5 lb_f bf be used to operate the mechanism. This value was measured with a spring scale.

Arduino Power Demand was a requirement we used when we had the secondary coil be the main power source for the Arduino. Now that we have shifted to a motion-sensitive stimulus for the LEDs, this specification is no longer needed.

No requirements or specifications are variable enough to require replication.

INTELLECTUAL PROPERTY

Nikola Tesla demonstrated the idea of electrostatic induction in 1891, using an alternating current in one coil to transmit a voltage to a separate coil. This museum exhibit can't be categorized as a new invention, because we haven't added anything to it or used it to perform a new task. Instead, this is merely an exhibition of a previously existing technology. While using an induction coil in a science museum exhibit is new for the RMSC, it has been done in other museums and thus is not a novel idea. A relevant patent category is: *G09B23/18 exhibit museum induction* where G09B23/18 is: "Models for scientific, medical, or mathematical purposes, e.g. full-sized devices for demonstration purposes for physics for electricity or magnetism".

Also important to note, is that science museum exhibits are rarely patented in the United States. This would make it difficult to find a reason to patent, even if the idea was novel, since most reasons to patent are financially justified and few people would be interested in investing in this product. The combination of these two facts makes this museum exhibit unpatentable.

SOCIETAL AND ENVIRONMENTAL IMPLICATIONS

The goal of this wireless charging exhibit is to educate children about how wireless charging works and its applications in the real world. Including this exhibit as part of the science museum's *How Things Work* exhibit will work to further the RMSC's mission to educate the public on technological concepts. This exhibit will teach visitors about how wireless charging works and also shows how wireless charging is applicable for aspects of everyday life such as charging one's phone. One drawback is that some kids may not understand the connection of how wireless charging works since there isn't an easy visual way of simulating each individual electron.

One ethical issue in this project is that the exhibit does not actually utilize the wireless charging to power the lights. This is due to the low frequency of the alternating current, which can't create a strong and consistent enough magnetic field to power these devices currently. Although the stimulated response isn't actually induced by wireless charging, having the sensor turn on the lights based on proximity is a solid method of communicating the same concepts without relying on real wireless charging.

One ethical impact we analyzed is the effect the induced magnetic field might have on pacemakers. In analysis, the exhibit, in its current state, was calculated to be safe as long as the user did not bring their device within 4 inches of the coil. When the magnetic field of the powered coil was measured with a gaussmeter, the observed magnetic field did not surpass 0.15 mT at any location in the 4-inch region surrounding the coils—even when the probe was held directly against the coils. This indicates that there is no concern for pacemaker or other medical wearable interference from the exhibit.

In terms of the environment, this exhibit requires a lot of power as well as outlets in order to run the system. The circuit uses a 7.04V power supply and current was measured to be 2.88A. This results in a power usage of 20.275W. This is roughly the power usage of a small computer monitor. However, the exhibit setup currently has no auto-shutoff, so it uses large amounts of energy even when it's not in use. This needless power demand negatively affects the environment due to the carbon footprint of electricity usage. To improve the electrical efficiency the exhibit, better wire connections, better transfer of electricity between the coils, incorporation of a "sleep mode" and better circuit connectivity can all help save energy and power.

RECOMMENDATIONS FOR FUTURE WORK

To continue this wireless charging project, a few minor tweaks can be made to improve the interactive and educational components. One thing that can be improved is an update to the circuit on the moving coil so that the exhibit can use actual wireless transfer instead of faking it using a distance sensor. This can be done by continuing to troubleshoot the circuit on the receiving side testing whether a higher current, more power, a change in coil geometry, might improve the power transfer. This might also involve searching for locations in each circuit where the power drop occurs to see if the signal can be amplified better.

Another suggestion is to improve the visual aid of electron behavior. Originally, the lights were supposed to gradually circle around the model phone or coils as the second coils were getting charged.

Something that may work is using Styrofoam balls or something that can represent an electron and will move when getting charged. This improvement can help children piece together that there is something happening when wireless charging happens, and it is more than what the eye can see. This does not necessarily have to be part of the moving wire assembly and perhaps could be housed on the side or another surface of the exhibit.

The immediate next step if we had more time would be to conduct more audience testing and installing an automatic shut off sensor so our exhibit does not over heat or waste energy when it is not being used. A typical RMSC exhibit goes through three or more rounds of audience testing before it is permanently installed on the museum floor. During design day, we plan to record further observations of public interaction as a set of supplementary materials for the museum to use if they choose to move forward with this exhibit idea.

ACKNOWLEDGMENTS

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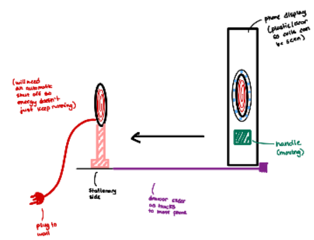
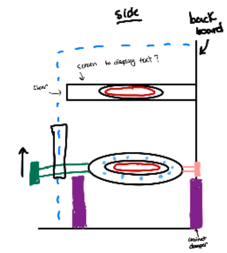
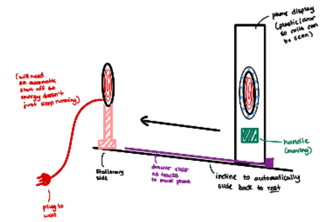
[2] "Magnetic Field Calculator for Coils and Solenoids." *Magnetic Field Calculator for Coil*, www.accelinstruments.com/Magnetic/Magnetic-field-calculator.html.

ANNEX A

Pugh Matrix Concept

Concept	Baseline	Vertical	Inclined
	 Fig. 1	 Fig. 2	 Fig. 3
Ease of Use	0	0	0
Intuitive use	0	-	0
Ease of Manufacture	0	-	+
Safety	0	0	+
Total	0	-2	+2

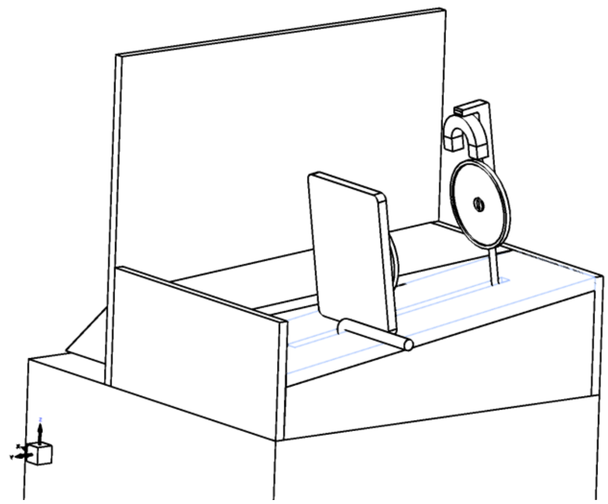


Fig 4: Final Concept Design

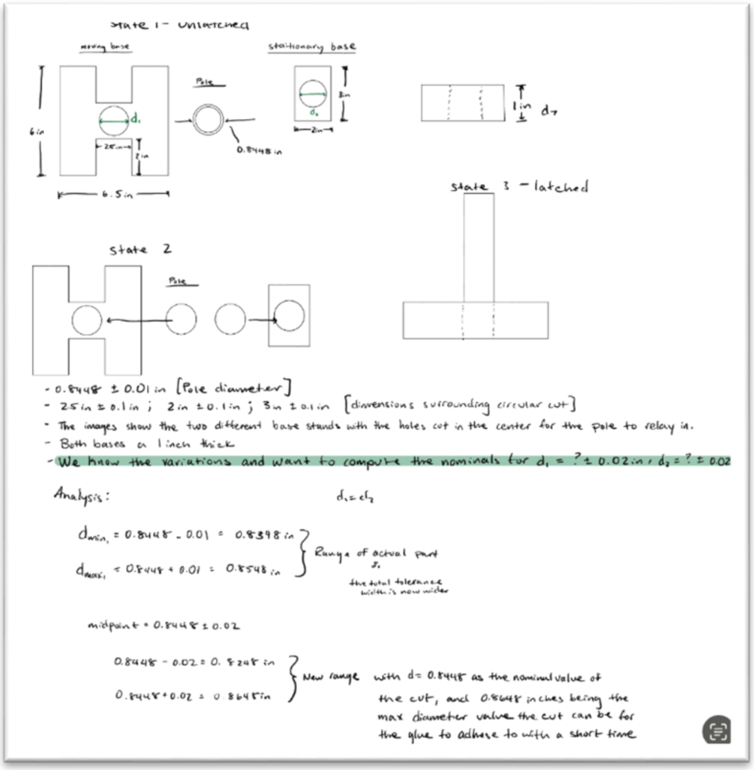


Figure 5: Tolerance Analysis

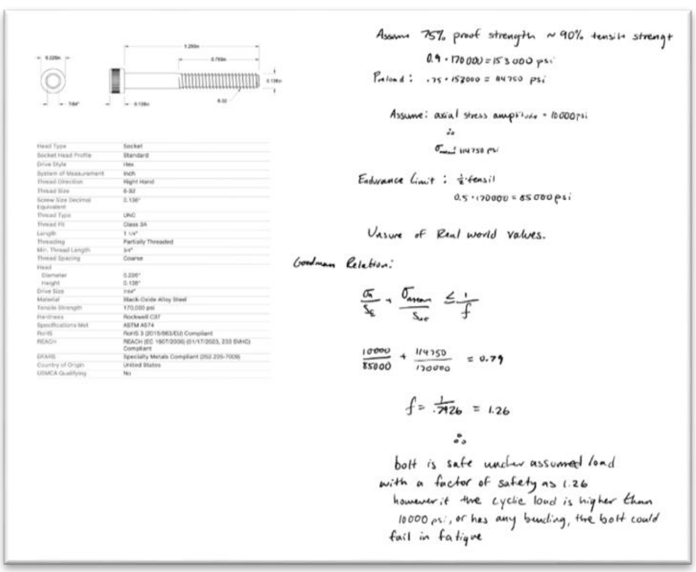


Figure 6: Fatigue Analysis

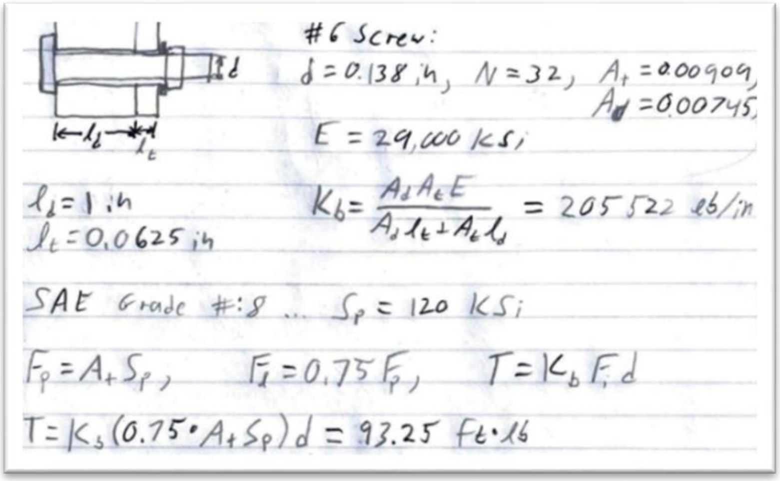


Figure 7: Torque Analysis Calculation

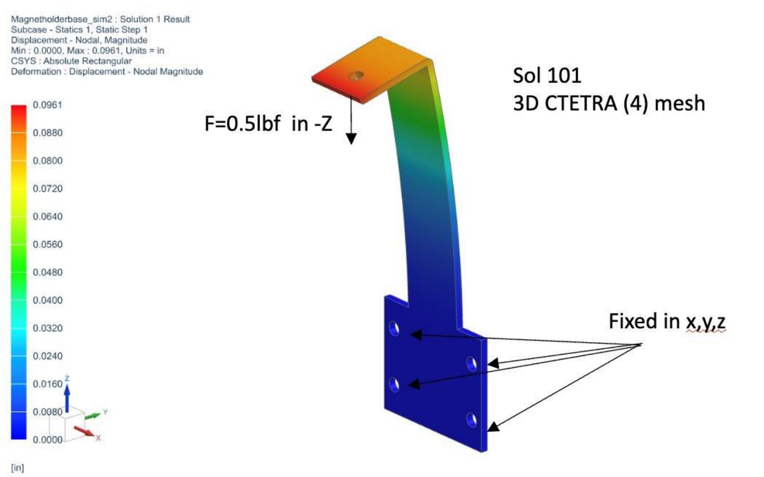


Figure 8: FEA analysis simulation on interactive magnet holder base

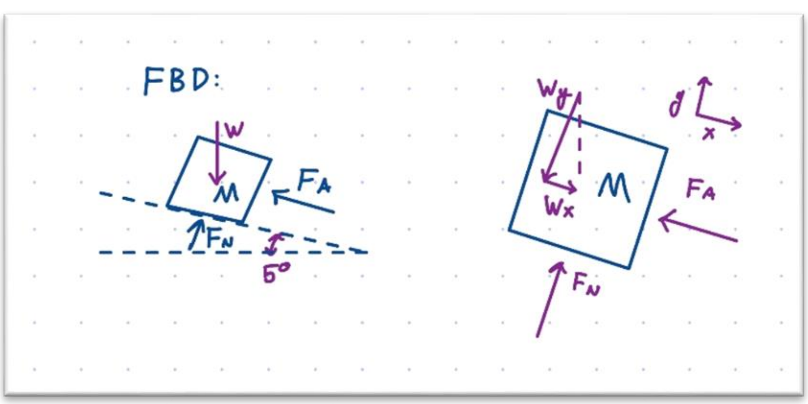


Figure 9: Statics Model of Moving Coil

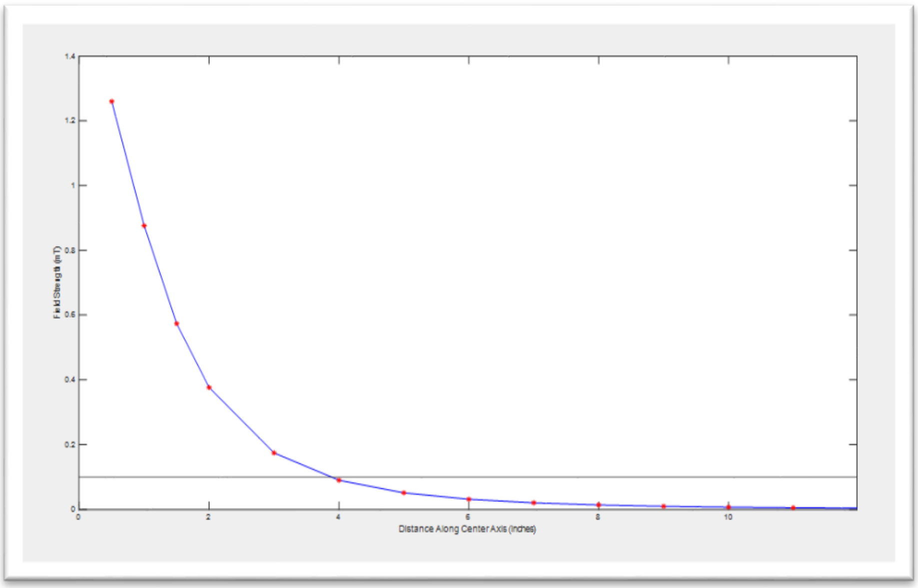


Figure 10: Graph of Magnetic Field Strength

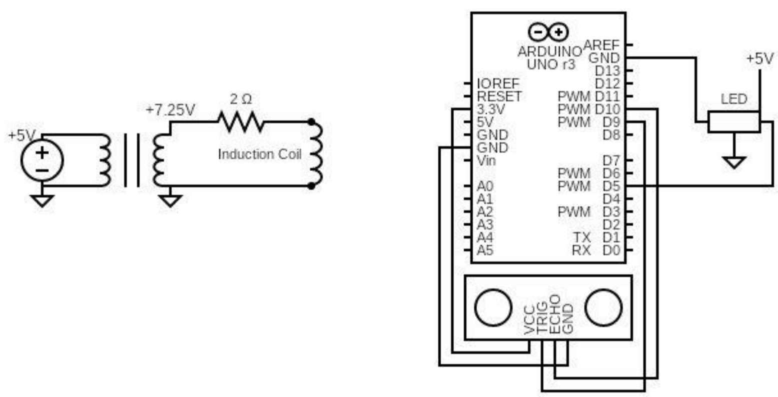


Figure 11: Circuit Diagram

```
%% Statics Analysis
% Katie Jarvis 4/27/25 version 1
%note: assusme we can go between lbf and lbm
sFric=2*10^-3;
angle=5; %angle of platform
%% Volumes
Vblock=26.3619; %volume of moving stand, in^3
Vdisk=9.6186; %volume of coil holder, in^3
Vphone=8.5*11*.75-1; %volume of the phone in^3
%% Lengths
Lpipe=10/12; %length of PVC pipe, ft

%% density
Ppf =.180; %schedule 40 PVC pipe .84 OD
dPVC = 1.4*0.0361273; %density of PVC block, in lbf/in^3
dpolycarb = 1.20*0.0361273; %density of polycarbonate lbf/in^3
dplywood=0.02;
%% masses
mc=96.43*0.00220462; %mass of coil, grams to pounds mass
mr=0.5; %mass of one half of a rail, lbf
mspacefiller=0.045; %mass of 3d printed plastic filler
mdisk=Vdisk*dpolycarb; %mass of polycarbonate disk
mpipe=Lpipe*Ppf;
mblock=Vblock*dPVC;
mphone=Vphone*dplywood;
M=mc+2*mr+mspacefiller+mdisk+mpipe+mblock+mphone
%mass of everything in pounds
% Equilibrium

Wx=(angle)*sind(5);
Wy=M*cosd(angle); %normal force

Fa=Wy*sFric+Wx %force applied needed
```

Figure 11: Code for Statics Calculations

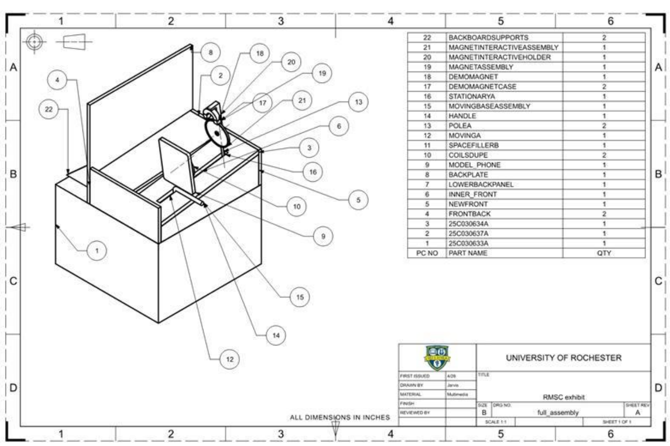


Figure 12: Bill of Materials and Final Assembly