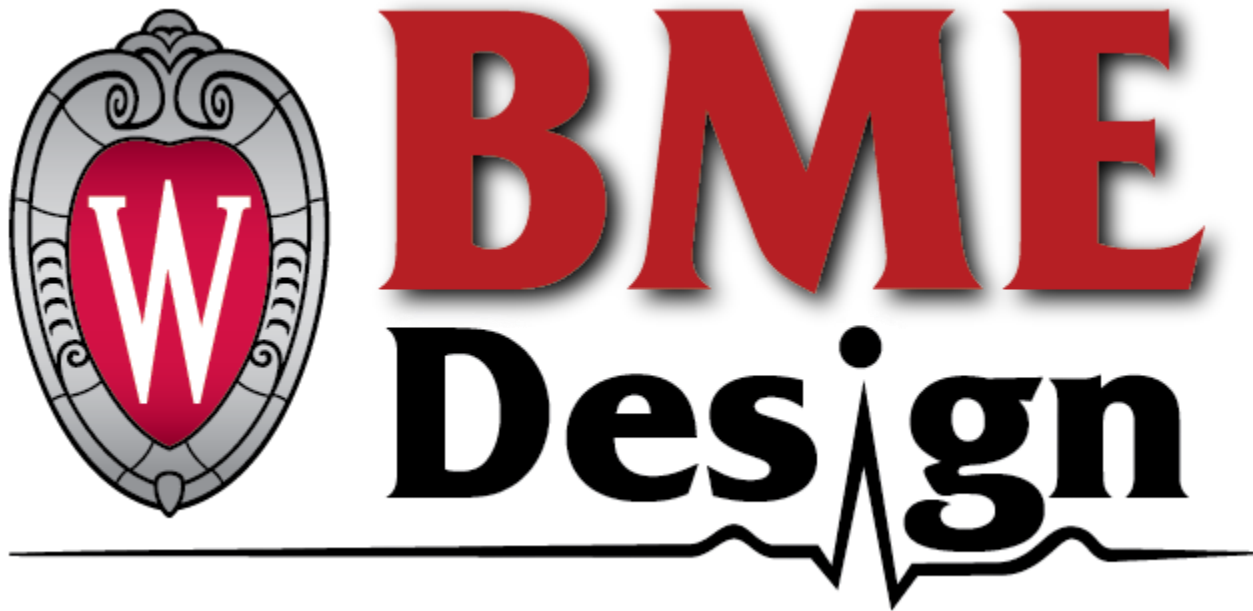




Primate Portal

BME 200/300

10/10/2025

Client: Dr. David Herzfeld – Department of Neuroscience

Advisor: Dhananjay Bhaskar

Team Members: Logan Olivera (Co-Leader), Kalob Kimmel (Co-Leader), Sameer Bhatt (BWIG), Andrew Dirkse (BSAC), Jackson Stewart (Communicator) and Charlie Fischesser (BPAG)

Abstract

Nonhuman primate (NHP) research plays a critical role in understanding complex neural behavior. Traditional training methods involve significant human interaction that can reduce data reliability. This project aims to design and

prototype an affordable, safe, and modular in-cage training device. This device enables positive reinforcement learning without researcher intervention. Current systems such as the Thomas In Cage Training System provide functionality but are expensive while lacking modular modification. Our proposed solution integrates a touchscreen, raspberry pi controller, and peristaltic pump to dispense liquid rewards following the correct completion of a task. The casing constructed of machined metal allows for durability and electrical safety complying with IEC 60601 and the Animal Welfare Act. The testing focuses on pump reliability for dispensing accurate amounts of juice, waterproofing, and mechanical stability. Results will demonstrate safety and standard compliance, while providing a low cost, modular approach for cognitive research with NHP. This device will offer a scalable product for future neuroscience applications that emphasize experimental precision and animal wellbeing.

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Introduction

Motivation and Global Impact

Understanding the advanced cognitive mind of nonhuman primates (NHPs) has the potential to advance the field of neuroscience and make an impact on the world of biomedical research. Traditional research methods rely on human interaction with the NHPs during the training; however, a device that limits human-NHP interaction and is designed to be used exclusively by the NHP would improve the quality of research by reducing NHP stress. Positive reinforcement training leads to meaningful results by reducing the stress and increasing the motivation of NHPs [1]. For example, an NHP might be consistently rewarded with juice or an edible prize for successfully completing a task. We have designed the Primate Portal device to utilize the principles of positive reinforcement learning, rewarding the NHP with juice for successful inputs. Our system is going to contribute to ethical research practices using the 3 Rs: replacement, reduction, and refinement [2]. The Primate Portal will advance scientific data collection while maintaining the wellbeing of NHPs.

Existing Designs

While several in-cage primate training systems have been developed in the scientific literature, the only commercially available design is Thomas RECORDING's InCage Training System (ICTS) [3]. The Thomas ICTS is a cage-mounted device that contains a shock- and waterproof touchscreen. It supports connections to external devices to upload data as well as operate eye trackers or other cameras. However, the device has several drawbacks, including limited software extensibility and a prohibitively high cost of roughly \$100,000. Because of the limited number of commercially available designs, an inexpensive and extensible design is highly desired in the neuroscience research community.

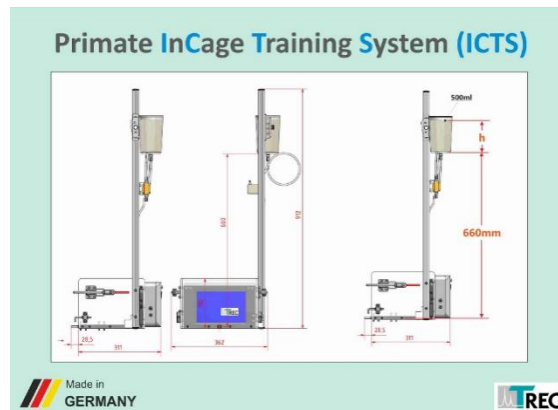


Figure 1: Thomas Primate In Cage Training System

Problem Statement

Research with NHPs can be difficult for researchers and NHPs and lead to inadequate results if done incorrectly. Using a device that requires the researcher to remove the NHP from the cage can cause the NHP stress, potentially lowering the quality of the data collected, and requires the researcher to be present for the duration of the task, which uses up the researcher's time. There is a desire in the neuroscience research community for a safe, modular, and automated NHP training system that uses positive reinforcement to deliver rewards for completing cognitive tasks to research further about the complex cognitive systems of NHPs. The system must be easy to use, inexpensive, easily detachable for use with different cage units, compatible with the NHPs' home environment, and flexible for modifications and improvements in the future.

Background

Overview

As stated in the introduction, the overarching goal of this project is to provide research with the resources necessary to observe complex cognitive processes and how neural circuits control these behaviors. The types of processes studied range from moving an arm or leg to making a decision. Given the depth and complexity of behaviors studied by the Herzfeld lab, it is important that the animals being used possess a brain complex enough to produce the required neural response and activity to a given stimulus [4]. For these reasons, the main species to be studied in the Herzfeld lab, and the intended user of the Primate Portal device, is the rhesus macaque.

The rhesus macaque is a species of monkey native to south, central and southeast Asia. They have a lifespan of up to 40 years. In studying complex neural behaviors, it is imperative that the animal being studied has a somewhat similar brain structure/function to that of humans [5]. The rhesus macaque shares a 93% homology with humans [6], including a brain structure more closely related to humans than that of other animals used in research, such as mice [7]. With respect to the Primate Portal project and the research the Herzfeld lab conducts, it should be mentioned that the rhesus macaques can be trained to complete simple and complex tasks. These tasks range from basic motor control to memory-based recognition tasks, allowing for a quantitative assessment of learning.

Standards and Regulations

Due to their lifespan and learning ability, rhesus macaques are very commonly used when researching more complex cognitive processes. This also implies that all the standards and regulations regarding animal research must be followed. When working with any NHP, it is of the utmost importance that safety is considered throughout every aspect of the project and the following standards, regulations and codes outline this. First, the Code of Federal Regulations, Title 9, chapter 1, subchapter A, part 3, subpart D, focusing on the specifications for the humane handling, care, treatment, and transportation of nonhuman primates, must be followed [8]. This states that the device must be safe, having no sharp edges, free cabling, toxic materials, or other hazards. This aligns with what the Institutional Animal Care and Use Committee (IACUC) requires during NHP research inspections [9]. IACUC can be thought of as “the FDA for animal research”. IEC 60601 is an international standard regarding electrical safety for devices which could be used in a lab setting. Compliance with this standard is crucial to ensure the safety of the NHPs. Another standard that must be followed is the Animal Welfare Act (AWA), specifically title 9 section 3.89 [10], which states that the device must be secured and that enough liquid must be given to the NHPs. As outlined in the requirements, all nonhuman primates must be given water every 12-24 hours. 9 CFR §3.75 Housing facilities, general also applies: in particular, the device must be “free of excessive rust” and “jagged edges or sharp points that might injure the animals” [11]. The device should also be able to be cleaned regularly. Lastly, the *Guide for the Care and Use of Laboratory Animals* should be followed throughout the design process of the primate portal project to ensure an ethical and safe design for the rhesus macaque [12].

Background Research

As a basis for the Primate Portal project, there are a couple of fields which need to be understood and researched to successfully design the device. The main topics researched consist of how the electronics will work, what types of applications the primates interact with as training, what materials should be used for the mechanical aspects, what liquid reward system should be used, and, lastly, research regarding the primates themselves (Overview section in background).

Looking at the circuitry and electronic system, the team researched multiple different components, which will be discussed and utilized later in the Design section of this report. Some important details of the circuitry must be noted. When using any motor or pump, back emf (electromotive force) must be considered—in this case, with the peristaltic pump. As the current in the solenoid of a motor changes rapidly (e.g. when turning the motor off), the magnetic field in turn will change rapidly, creating a current in the opposing direction [13]. This opposing current is called back emf and can be very harmful to the system. To prevent back emf from causing harm to any electronic system, the flow of current must

be controlled, meaning it must only be able to travel in one direction. This can be fixed using a one-directional diode to force current only in one direction. Otherwise, any components that interact directly with the pump must be able to withstand the back emf created by the pump. More research was done to understand the basics of a raspberry pi as well as how it can be used to control hardware. A Raspberry Pi is a small, cheap computer generally used to control small systems, such as the Primate Portal. The Raspberry Pi has many applications, but in the context of the Primate Portal, the focus is on how the GPIO (general purpose input/output) pins are laid out and how they can be used to input and output signals [14]. Shown below in Figure 2 is the GPIO layout of the Raspberry Pi 3B+.

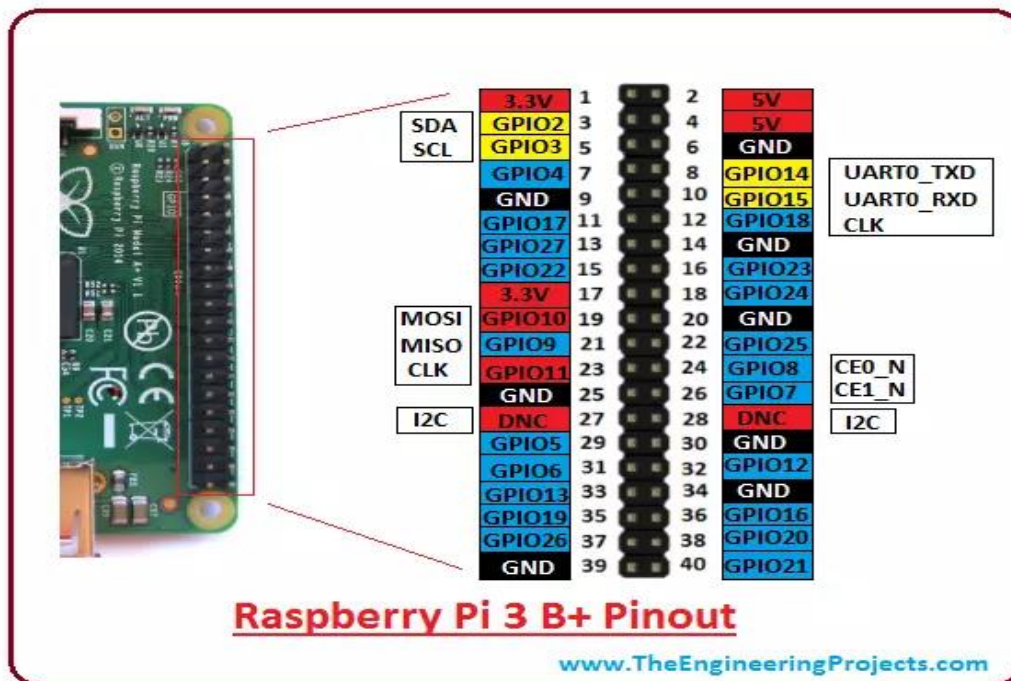


Figure 2: Raspberry Pi 3B+ GPIO pin layout

Another important consideration of this project is the type of material that will be used as the general enclosure containing the electronics. A few materials were researched, with the most notable being aluminum and steel. Generally, steel is a stronger and more durable material, but it is much harder to use during fabrication than aluminum. Figure 3 below shows some general characteristics of both steel and aluminum and how they compare to each other [15].

Property	Steel	Aluminum
Cost	Low	Moderate
Ultimate Tensile Strength	400 – 2000+ MPa	75-500 MPa
Density	0.28 lb/in ³	0.1 lb/in ³
Corrosion Resistance	Low (carbon steel) to moderate (stainless steel)	High
Malleability	Low	High
Machinability	Moderate	High
Weldability	High	Low
Castability	Low	High
Application Examples	Construction, infrastructure, automobiles, appliances, tools, fasteners	Aircraft, electrical wiring, electronics, utensils, foil

Figure 3: Comparison table of both steel and aluminum

Client Information

The client for this project is Dr. David Herzfeld, an assistant professor affiliated with the Department of Neuroscience at the University of Wisconsin–Madison [16]. Furthermore, he is the director of a lab that studies how neural circuits can control complex behaviors in animals and how large populations of neurons are activated to perform a given response, with the use of computational modeling to link the behavior to neural activity [4].

Product Design Specification Overview

As per appendix A, the following is an overview of the primate portal specifications that should be met. As general performance characteristics, the device is to be used daily, being loaded and unloaded in the morning and night respectively. The project itself has a budget of \$5000. The device must comply with IEC 60601 and the Animal Welfare Act. Overall, the system must handle failures by giving SMS notifications to the operator and shutting down the entire system immediately. It is of most importance that the system does not improperly train the primates. Each of these topics is covered in greater detail in section A of the appendix.

Preliminary Designs

Integrated Circuitry Box Design

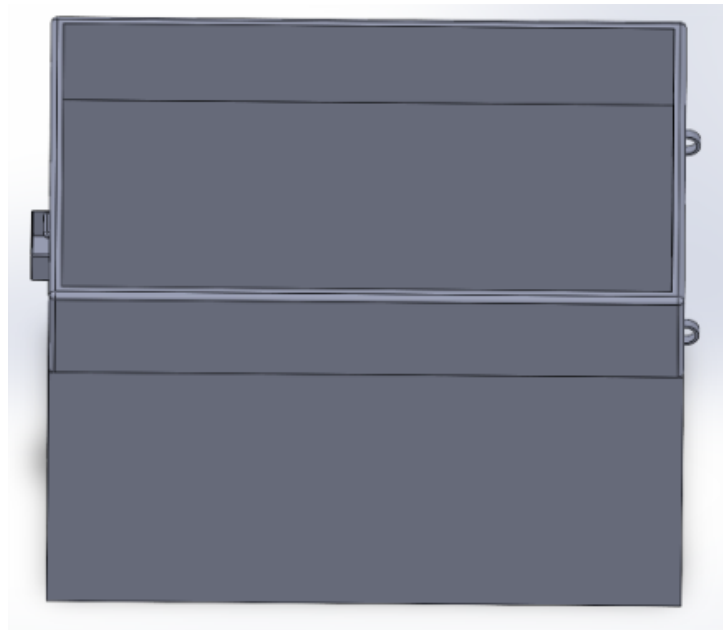


Figure 4: CAD model of integrated circuitry box design

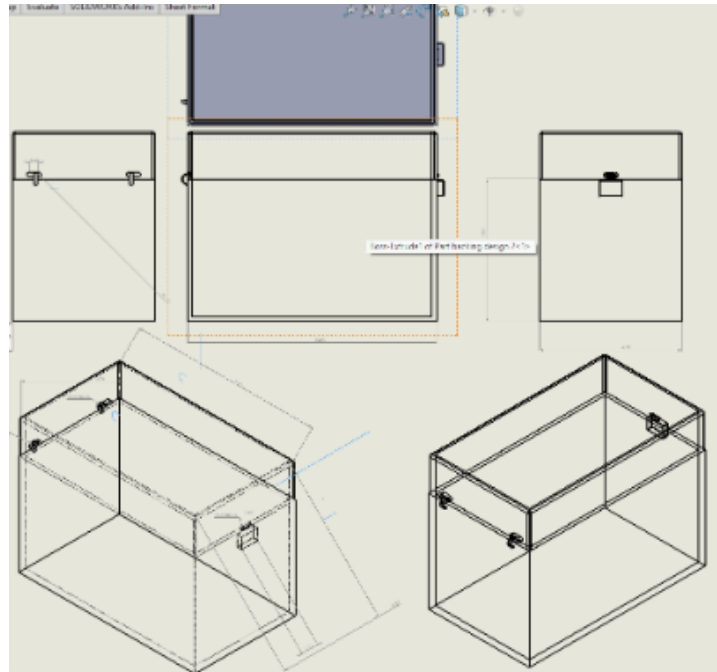


Figure 5: CAD drawing of integrated circuitry box design

The integrated circuitry box design is very compact. It combines the screen casing with the circuitry box. It does not have a dedicated pump housing, so the nozzle could be moved with research needs. The design has a detachable hinge on the right, and a latch on the left. This will attach around the cage with the display on the inside and the circuit box on the outside.

Lateral Nozzle Design

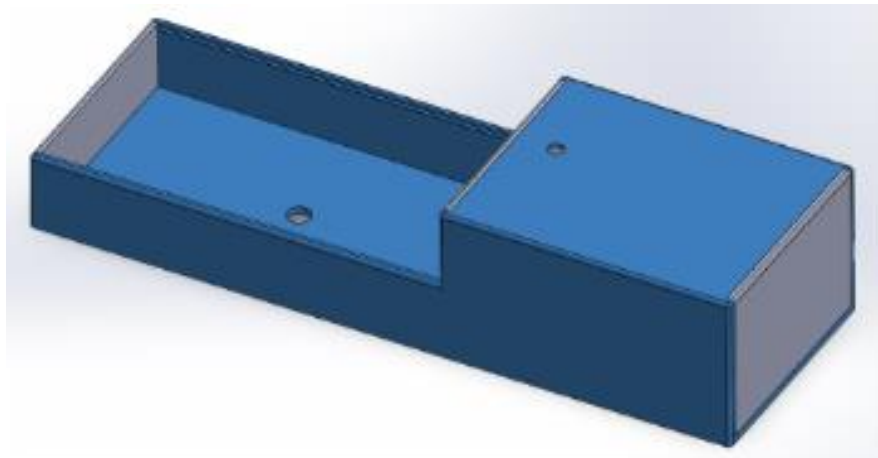


Figure 6: CAD model of lateral nozzle design

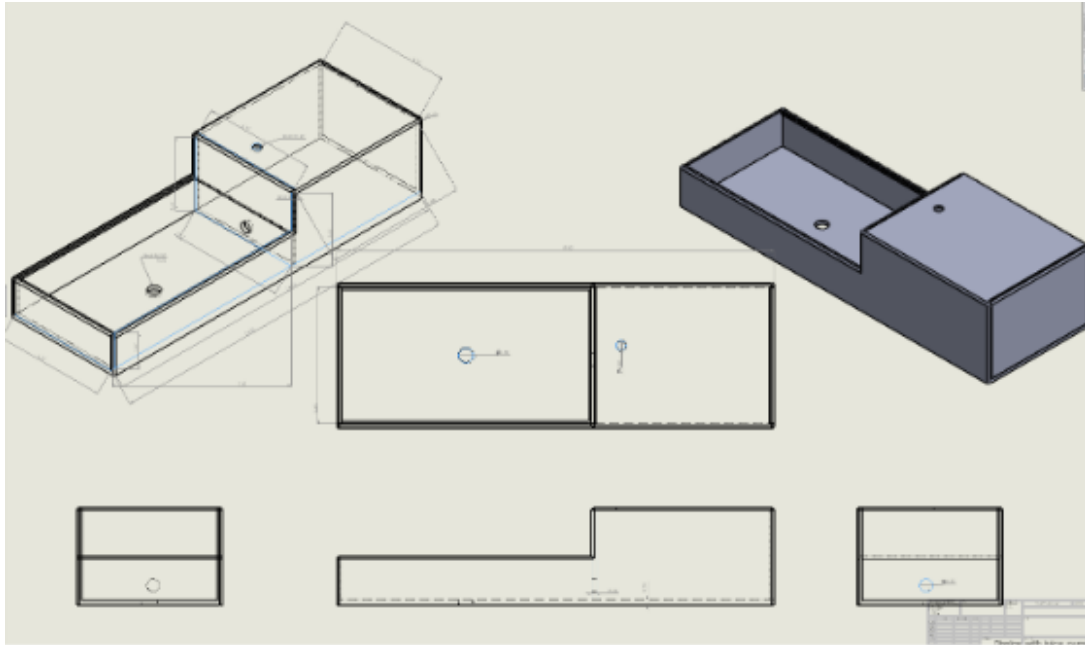


Figure 7: CAD drawing of lateral nozzle design

The lateral nozzle design has a hole for the nozzle to the right of the compartment for the touchscreen. The touchscreen compartment has a hole for wiring. Per our client, the monkey will likely have its mouth at the nozzle for most of the duration of the experiment, so it will be performing the experiment on the touchscreen while looking to the left.

Longitudinal Nozzle Design

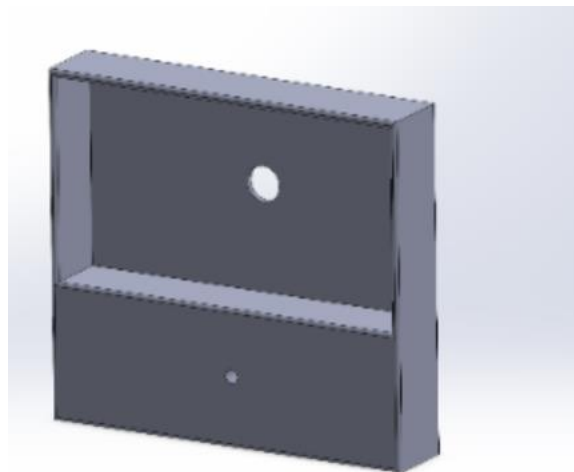


Figure 8: CAD model of longitudinal nozzle design

The longitudinal nozzle design has a hold for the nozzle under the compartment for the touchscreen. The touchscreen compartment has a hole for wiring. Per our client, the monkey will likely have its mouth at the nozzle for most of the duration of the experiment, so it will be performing the experiment on the touchscreen while looking up.

Preliminary Design Evaluation

Design Matrix

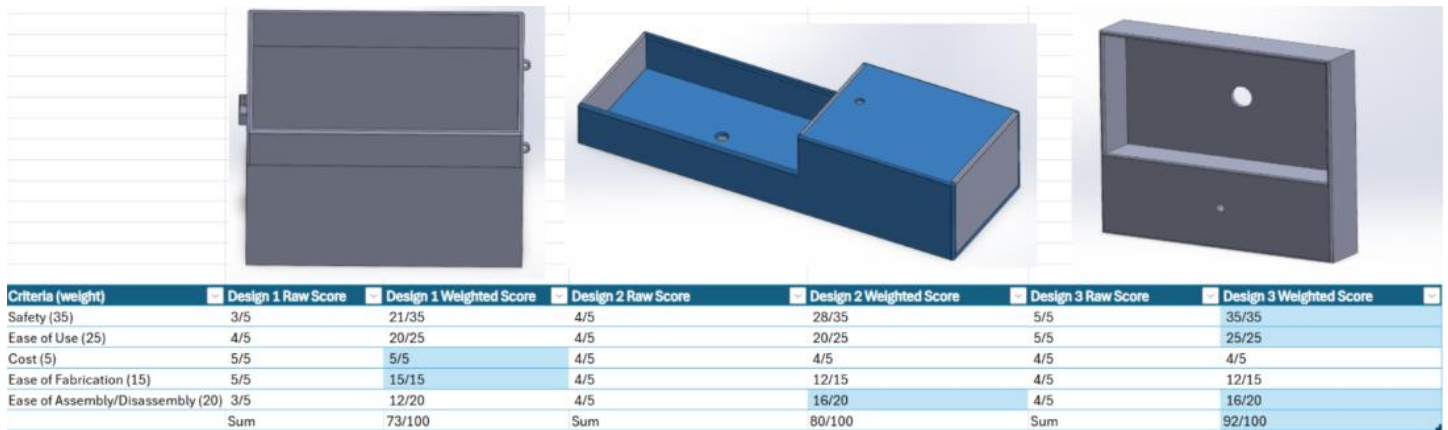


Figure 9: Design matrix

Design Criteria

Safety (35) – The safety of the device is the most important part of the design. The device will be used by intelligent nonhuman primates (NHPs) during regular hours. The device should restrict access to dangerous areas such as those with wires to the NHPs to ensure they cannot be electrocuted. The device must comply with 9 C.F.R. § 3.75 (c) Surfaces which state that surfaces that come into contact with NHPs must “be free of excessive rust” or “jagged edges or sharp points that might injure the animals”.

Ease of NHP Use (25) – The device will be used by the NHPs daily to continue their training away from the researchers. The device must be easy for the NHPs to use to ensure that research can continue and that NHPs learn how to effectively give data.

Cost (5) – Cost is not a major concern for us, as our client has expressed his agreement to fund our project up to the amount of \$5000.

Ease of Fabrication (15) – The device should be relatively easy to fabricate to allow the reproduction of the product by our client in the future. This means that it should require minimal machining, circuitry, and coding to recreate.

Ease of Disassembly and Reassembly (20) – The device should be easy for the user to disassemble and reassemble. The device should be easily taken off and put back on the cage during daily cleaning of the cage in a way that does not disturb the NHPs.

Design Scoring

Design 1:

Safety: 3/5, Relatively safe, but NHPs are closer to wires, and they may be easier to access, which could be dangerous. The seams between the touchscreen casing and the circuitry box casing may also be large enough to allow urine inside, possibly resulting in electrocution of the NHPs.

Ease of Use: 4/5, Very easy to use for the NHPs. The freely movable nozzle means that the researcher can set it anywhere that they see fit, possibly resulting in new ways to test the device. However, this nozzle would be harder to secure to the cage, so if the NHPs pulled it off of the wall of the cage, the device would not work properly.

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Cost: 5/5, This design is very cost effective because it would only require the materials to make two five-sided-boxes to house the touchscreen and circuitry systems.

Ease of Fabrication: 5/5, This design would be the easiest to fabricate due to it only being two five-sided-boxes held together. This could easily be done by welding five plates together or by hollowing out a metal cube, but the latter may cost significantly more to produce.

Ease of Disassembly and Reassembly: 3/5, This design may be harder to assemble and disassemble because the touchscreen cannot slide out, meaning that we would have to install an easily removable system to each part of the casing for quick assembly and disassembly.

Design 2:

Safety: 4/5, This design is very safe, but the NHPs may be able to access the touchscreen and pump systems via the removeable side panels because they do not have a locking mechanism to keep them in place.

Ease of Use: 4/5, This design is very easy for the NHPs to use, but their heads would be to the side of the screen while using the device, so it may restrict their ability to see the screen and effectively use the device.

Cost: 4/5, This design would cost more than the first design because of the need for more material and machining. The side panels and extended pump casing would require more metal than the plain five-sided-box that would be used for the touchscreen in our first design.

Ease of Fabrication: 4/5, This design would be relatively easy to fabricate because it only requires a few boxes to be made of metal. However, the added material and complexity compared to our first design would make it slightly harder to manufacture.

Ease of Disassembly and Reassembly: 4/5, This design would be very easy to assemble and disassemble because the side panels can be removed to quickly remove the touchscreen and pump systems to collect the stored data.

Design 3:

Safety: 5/5, This design is very safe for the NHPs. The touchscreen and pump systems would be fully protected thanks to the locking mechanism on the side panels, and the circuitry box would not be exposed to any urine during use.

Ease of Use: 5/5, This design would be very easy for the NHPs to use because they would be able to sit directly underneath the screen while using the device. They would not have an obstructed view of the screen as their eyes would be at roughly the same height as the screen.

Cost: 4/5, This design would cost more than the first design, but about the same as the second design because of the need for more material and machining. The side panels and extended pump casing would require more metal than the plain five-sided-box that would be used for the touchscreen in our first design.

Ease of Fabrication: 4/5, This design would be relatively easy to fabricate because it only requires a large box with a divider to be made of metal. However, the added material and complexity compared to our first design would make it slightly harder to manufacture.

Ease of Disassembly and Reassembly: 4/5, This design would be very easy to assemble and disassemble due to the removeable side panels that allow easy access to the touchscreen and pump systems for data collection. These panels would be easy to remove for a researcher as they would be locked into place with a mechanism similar to that used in crutches.

Final Proposed Design

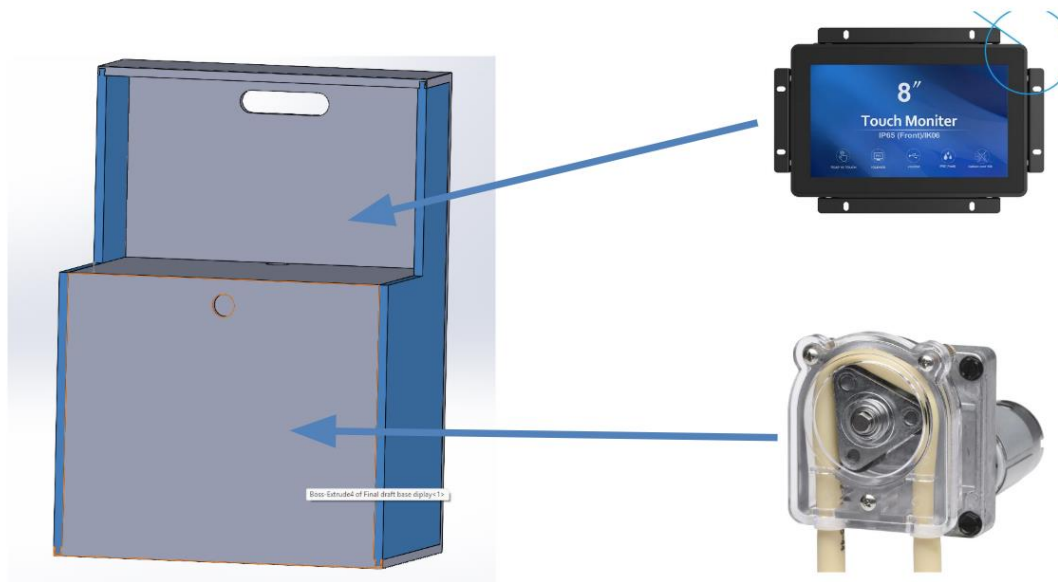


Figure 10: Final proposed design of the device

In the final proposed design, the circuitry is enclosed in the bottom part of the integrated circuitry box along with the peristaltic pump. The juice output extends through a hole in the front of the box. The touchscreen sits in a slot in the top part of the integrated circuitry box and is held in place by a locking mechanism like that used in adjustable crutches. The touchscreen is connected to the Raspberry Pi by wires that run through a hole in the top part of the box. The match-to-sample task software is run by the Raspberry Pi to receive input from the touchscreen, store data on the microSD card, and send signals when appropriate to the pump to dispense the reward.

Fabrication

Materials

The materials needed for the project are separated into two categories, the electronics portion and the mechanical portion. The electronics portion includes all the hardware used to create the circuitry and functionality of the final product. The materials included in this category are a Raspberry pi, a Micro SD, a motor controller, a peristaltic pump, a power supply, a touchscreen, and wiring to connect all of that together. The mechanical portion includes the casing and subsequent safety features. The materials for this category are a 2 square foot aluminum sheet, four 0.1 inch diameter springs, four 0.1 inch diameter steel balls, two key locking mechanisms, a magnetic contact sensor, two steel hanging bars, and two clamping mechanisms.

Methods

The start of the fabrication process is the electronics portion. This starts with the raspberry pi. The raspberry pi is the brain of the electronics portion, and it controls the touchscreen, the magnetic interlock, and the motor controller. The display is connected through HDMI, the motor control is connected to pins 23 and 26, the magnetic interlock will also connect. The motor controller connects to the pump and protects from back emf. The power supply connects to the touch screen, the raspberry pi, and the motor controller. It supplies 12V to the touch screen, and 24V to the motor controller. There is a micro-USB that connects the raspberry pi that controls the power supplied to the raspberry pi.

The second part of the fabrication process is the mechanical portion. The first part is creating the casing out of the aluminum sheet. This is comprised of two main parts, the body and the doors. The body is created by bending 2 inches

and 5 inches the long way on a 7.4 inch wide part of the aluminum sheet. The total length of the sheet used is 17.5 inches, and the length after bending is 10.5 inches. After this bend another sheet at 6 inches, with 17.1 inch width and 11 inches long. The first sheet used will have a 1/4 inch slot drilled 1/2 inch from the 2 inch bend. The second sheet will have a 1/4 inch hole drilled 1/2 inch from the crease on the 6 inch side, and another one drilled on the 5 inch side 4.5 inches from the crease. These two pieces are then fastened together. There are then four hallways drilled on the 0.2 inch sides of the 2 inch and 5 inch walls. At the top of these hallways there will be .06 radius holes drilled .2 inches from the top the rest of the way through that allows for locking of the doors. This brings us to the second part of the case. The doors are created by cutting out two 10.4 by 5 inch section of aluminum out of the sheet. Then take 4.25 inch by 3 inch section out of both doors. From here create the hallway inserts. These are 0.15 inches from each edge. Take off an angled portion that matches the hallway. This creates a snug fit that only slides vertically. Then drill 0.1 inch diameter holes 0.1 inches into the hallway insert face .2 inches from the top to match the hallway holes. From here you insert buttons made from the steel balls and springs in the hole which acts as the vertical locking mechanism for the door. This completes the casing. From here insert the magnetic interlock on the edge between the door and base of case, apply clamping mechanisms and steel hangers on the back of the case with appropriate cage length. This varies by cage, and finally apply the locks on the clamps to ensure that there is no tampering.

Final Prototype

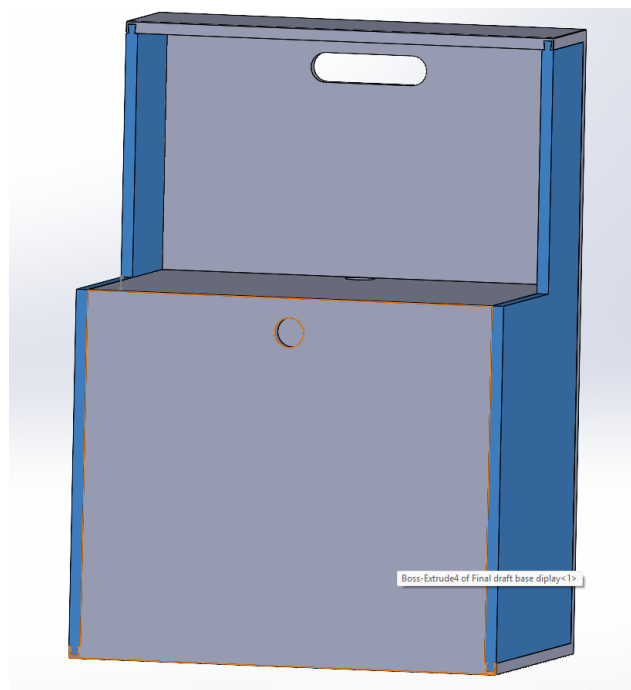


Figure 11: Final prototype CAD model

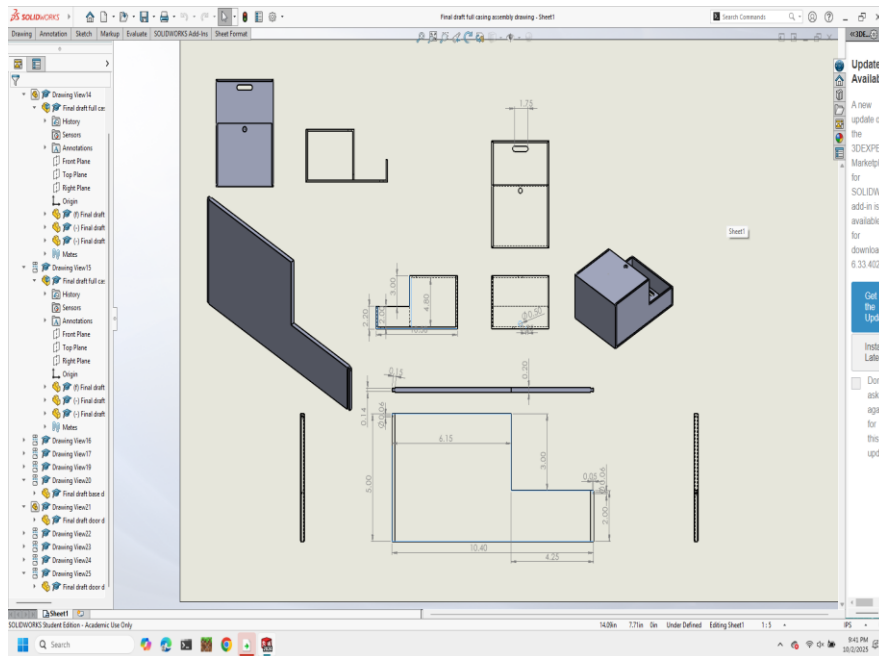


Figure 12: Final prototype CAD drawing

Testing

The team will test the viability of each of our final product components to evaluate its ability to properly dispense juice when an activity is completed successfully by the primates in accordance with our design specifications. Below are included in the 3 key categories that must be tested.

Electronic and Software Accuracy Testing

The electronics ability to accurately dispense the correct amount of juice will be tested thoroughly. As the product will be used in an experimental setting, the goal accuracy is 100% because if it is incorrect, the entire experiment results will become unusable. This will be tested by humans in 100 trials who will correctly finish the task and should receive juice to ensure the goal of accuracy is met. In addition, another test for accuracy is the amount of juice which will be dispensed. As cited in the PDS, the primates should be given 10 mL of juice per successful task with a margin of error of ± 1.5 mL [Appendix A]. This will be tested over 20 trials to develop proper variance measurements with the juice being pumped into a graduated cylinder to measure how much is being dispensed.

Mechanical Waterproof Testing

The mechanical design's waterproofing ability must be tested to ensure safety of the primates. Although there is not a quantitative test to measure this, there is a 0% tolerance for water entering the device because of safety concerns. The device must be waterproof to jets up to 3 kPa as that is the most pressure a primate could generate while urinating [17]. To test this, at all edges or points where water could enter the device, there will be striped places and after a 3 kPa jet is aimed at the device for ~10 seconds the strips will be analyzed to see if water made it into the device. A successful test would be one where none of the strips have any water on them.

Mechanical Sturdiness Testing

The mechanical design sturdiness must be tested to ensure the primates cannot move the device at all. The goal force it must be resistant to is 150 N[18]. To test this, the product will be latched onto the cage, and humans will apply ~150 N force from every direction to test if the device can be moved in any of those directions. Although there isn't a

quantitative result which can be derived from this test, due to safety concerns, a successful test will be one in which there was no movement of the device in any direction.

Discussion

As of the current state of the project, not much can be said in this section regarding any results or implications of the design. It is intended that the primate portal will compete with other designs on the market (i.e. Thomas recording system) and follow all of specifications outlined in the PDS (section A of the appendix). No changes are to be made yet as the initial design is still being developed.

Conclusions

Conclusion

The goal is to design and implement a mountable touchscreen device that will train primates via positive reinforcement by administering an automated liquid reward based on primate cognitive inputs on touchscreen. After discussing with the client, the team decided that the most efficient design would be the longitudinal design. This final design will consist of a vertical design with the top section focused on touchscreen and bottom section focused on pump and circuitry storage. The circuitry will run through a Raspberry Pi, sending signals to the pump after correct inputs on the touchscreen. Currently, the team is working on prototyping with cheap materials to understand potential future structural issues with the desired material, aluminum. The team has also been focused mainly on mechanical and software parts of the project, while the electrical side has not been discussed much.

Future Work

The team plans to prototype in the upcoming weeks. The beginning is going to consist of hardware testing with the software that has been made. At the same time, there will be a focus on mechanical testing, focusing on how the device will sturdily connect to the cage, yet be easily detachable for the researchers. The team also is planning on discussing the electrical components more in-depth, mainly focused on how the circuits will be powered in a safe environment away from the primates. In the future, the team will run stress tests using SolidWorks programs to determine the breaking point of the device and structural implications.

References

- [1] M. Bloomsmith, K. Neu, A. Franklin, C. Griffis, and J. McMillan, "Positive reinforcement methods to train chimpanzees to cooperate with urine collection," *J. Am. Assoc. Lab. Anim. Sci.*, vol. 54, no. 1, pp. 66–69, Jan. 2015.
- [2] "The 3Rs." National Centre for the Replacement Refinement & Reduction of Animals in Research. Accessed: October 11, 2025. [Online.] Available: <https://nc3rs.org.uk/who-we-are/3rs>
- [3] Thomas RECORDING. "Thomas InCage Training System." Thomas RECORDING. Accessed: October 11, 2025. [Online.] Available: <https://www.thomasrecording.com/thomas-incage-training-system-icts>
- [4] D. Herzfeld. "Herzfeld Lab." Herzfeld Lab. Accessed: October 11, 2025. [Online.] Available: <https://herzfeldlab.neuro.wisc.edu>
- [5] J. Fooden, "Systemic review of the rhesus macaque, *Macaca mulatta* (Zimmerman, 1780)," *Fieldiana Zool.*, n. s., no. 96, pp. 1–180, Jun. 2000, doi: 10.5962/bhl.title.7192.

BME Design: 200, 201, 300, 301, 400 and 402

[6] “Rhesus macaques (*Macaca mulatta*) in biomedical research.” National Primate Research Centers. Accessed: October 11, 2025. [Online.] Available: https://www.nprcresearch.org/research/page/Rhesus_Macaques_%28Macaca_mulatta%29_in_Biomedical_Research

[7] A. J. Cauvin, C. Peters, and F. Brennan, “Advantages and limitations of commonly used nonhuman primate species in research and development of biopharmaceuticals,” in *The Nonhuman Primate in Nonclinical Drug Development and Safety Assessment*, J. Bluemel, S. Korte, E. Schenck, and G. Weinbauer, Eds., New York, NY, USA: Elsevier, 2015, pp. 379–395, doi: 10.1016/B978-0-12-417144-2.00019-6.

[8] Code of Federal Regulations, Title 9, part 3.89, 2025.

[9] S. D. Tardif, K. Coleman, T. R. Hobbs, and C. Lutz, “IACUC review of nonhuman primate research,” *ILAR J.*, vol. 54, no. 2, pp. 234–245, 2013, doi: 10.1093/ilar/ilt040.

[10] Animal Welfare Act, Title 9, section 3.89, 2023.

[11] Code of Federal Regulations, Title 9, part 3.75, 2025.

[12] *Medical Electrical Equipment*, IEC Standard 60601-1, International Electrotechnical Commission, Geneva, Switzerland, Jul. 2025.

[13] Fmarquis, “Control peristaltic pump with TA7291P and an Arduino.” Autodesk Instructables. Accessed: October 11, 2025. [Online.] Available: <https://www.instructables.com/Control-peristaltic-pump-with-TA7291P-and-an-Ardui/>

[14] “Physical computing with Python.” Raspberry Pi. Accessed: October 11, 2025. [Online.] Available: <https://projects.raspberrypi.org/en/projects/physical-computing/1>

[15] IMS Team. “Steel vs. aluminum: Understanding the difference between ferrous and nonferrous metals.” Industrial Metal Service. Accessed: October 11, 2025. [Online.] Available: <https://industrialmetalservice.com/metal-university/steel-vs-aluminum-understanding-the-difference-between-ferrous-and-nonferrous-metals/>

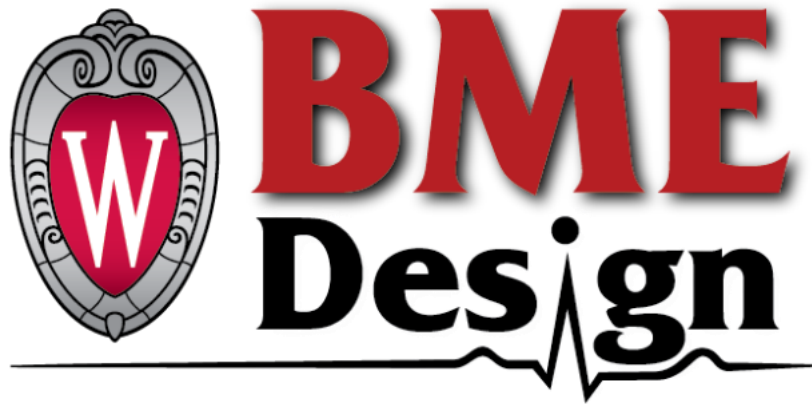
[16] “Herzfeld, David.” University of Wisconsin–Madison. Accessed: October 11, 2025 [Online.] Available: <https://biophysics.wisc.edu/staff/herzfeld-david/>

[17] T. Yamamoto, R. Sakakibara, T. Uchiyama, and S. Kuwabara, “The examination of detrusor underactivity in multiple system atrophy,” *Frontiers in Neurology*, vol. 15, Sep. 2024, doi: <https://doi.org/10.3389/fneur.2024.1460379>.

[18] I. S. Glover, D. B. Margetts, and T. L. Davidson, “Both corticospinal and reticulospinal tracts control force in handle-pull tasks in rhesus macaques,” *Journal of Neuroscience*, vol. 42, no. 15, pp. 3150–3162, Apr. 2022.

Appendix

A. Product Design Specifications



Product Design Specifications

09/18/2025

Primate Portal

BME 300/200 Section 304

Group Members:

Leaders: Kalob Kimmel and Logan Olivera

Communicator: Jackson Stewart

BSAC: Andrew Dirkse

BWIG: Sameer Bhatt

BPAG: Charlie Fischesser

Client: Dr. David Herzfeld

Advisor: Dr. Dhananjay Baskar

Function

The primate portal is intended to be a primate positive reinforcement training device. From a higher-level perspective, the primate portal is a touchscreen interface, outputting a liquid reward for the primate when it successfully completes a task on the touchscreen. From a more detail-oriented perspective, the primate portal is a touchscreen interface controlled by a Raspberry Pi. The Raspberry Pi contains a simple python-based user interface and database to train the primates (more specific software will be developed by client's research team). Once a correct input is received, the Raspberry Pi will output a signal to a peristaltic pump to reward the primate for its correct actions by dispensing a liquid of the operator's choice. The entire system will be safely

mounted to the primate's cage and enclosed in a protective box. Overall, the system is used to gain an understanding of the cognitive function of complex neural behaviors.

Client requirements

- Product must only dispense juice when primate successfully completes challenge
- Product must have notification system if primate isn't getting any liquid
- Product electronics must be enclosed and away from primate to ensure electrical safety
- Product touchscreen must be secure with no risk of falling off the cage bars
- Product must be easily put on and taken off by lab assistants
- Software must be easily modifiable to support different future experiments
- No incorrect training – failures stop reward output
- Highly emphasize safety
- Modular for future applications and studies
- Easy for operators to attach and remove cage
- Compatible with primate environment
- Data accessible through usb or ssh
- Minimal exposed wires
- \$5000 budget

Design requirements

1. Physical and Operational Characteristics

- a. **Performance requirements** – The primate portal product has three distinct fields in which it must meet different performance requirements. These fields are the circuitry/code of the design, the enclosure, and the peristaltic pump delivery system. The device is to be used daily, being loaded and unloaded at morning and night respectively.

As for the circuitry/code, there must be a well-defined and documented system in which, when there is a correct input passed (through the touchscreen display), a 5V pulse be output. This must be modular in the sense that it is very easy for an operator to develop a new training application that outputs the correct signal. This output will be further discussed when considering the peristaltic pump. As for a failure case, it is expected that the electronics of this system will not cause any harm to the user or operator.

Performance requirements with respect to the enclosure are of the utmost importance as to protect the users, operators and the primate portal system itself. The enclosure must be able to be easily mounted and removed from the cages holding the primates. It should be lockable in the sense only a human can remove the system, with interlocks connected to the electronics, providing a failsafe in the case the enclosure is mounted incorrectly. Most importantly, the enclosure must be safe, meaning no sharp edges, no exposed electronics and no accessible items

to the primates. In no way, shape or form, should the primates be able to damage or mess with the system when it is in the enclosure.

Lastly, the peristaltic pump has its own set of unique performance requirements. The pump must respond to the 5V signal sent from the microcontroller and accept a 24V signal (variable input but 24V standard) signal to activate the pump. Back EMF effects or any other mechanical related possible issues should be accounted for. The pump must be easily accessible to swap out and clean the tubing containing the liquid. Lastly, following the same pattern as the other performance requirements, the pump system must be safe.

- b. **Safety** – Safety is of the utmost concern in any biomedical device, and the primate portal is no exception. It is imperative that no injury can be sustained through use and setup of the device. As per IEC 61010-1 [1], the system must be operating under 60V, or it will need extra protection. Any current carrying wire must meet clearance regulations provided by IEC 61010-1, with a 3mm separation distance. No component in the system can exceed 60 degrees Celsius as to protect the primates. The IEC also outlines ingress protection ratings of which this device should fall under IP54 or better [2].

It is important to also consider the Code of Federal Regulations, title 9, chapter 1, subchapter A, part 3, subpart D, focusing on the specifications for the Humane Handling, Care, Treatment, and Transportation of Nonhuman Primates [3]. This states that the device must be safe, no sharp edges, no free cabling, no toxic materials or any other hazards. This aligns with what the Institution animal Care and Uses Committe (IACUC) looks for during primate research inspections. IACUC can be thought of as the “FDA” for animal research.

- c. **Accuracy and Reliability** – The touchscreen must be responsive to primate touch. The juice pump must deposit 10 mL with a ± 1.5 mL margin of error when the primate successfully completes a challenge. No failure should be seen on the software or hardware side and should be rigorously tested. The enclosure must be able to withstand forceful impact (primate punches and kicks), exposure to liquids and temperature changes without any faults. If anything fails, the system must stop training completely, notify the researcher of the failure through text message or email, and pause the output of the liquid reward until fixed.
- d. **Life in Service** – The primate portal is expected to be used daily for up to 8 hours a day. It should be fully functional for 3-5 years without fault (not accounting for consistent excessive tampering from primates). The peristaltic pump as well as the touchscreen display are expected to operate for the full 3-5 years.
- e. **Shelf Life** – The product should last upwards of ten years if not broken or tampered with. It should also be relatively easy to repair if it does break.
- f. **Operating Environment** – The product would be placed on the side of the cage with the touchscreen inside the bars and a unit with the Raspberry Pi and other critical components on the outside. The client has stated that the device may be exposed to urine and/or other primate excrement and thus must have a waterproof touchscreen and protected wiring and components.
- g. **Ergonomics** – The client has stated that the product should be easy to use for both the primates and the scientists. For the primates, the touchscreen should be easily accessible and large enough

to ensure training is completed correctly. For the scientists, the product should be easily removable from the cage and should allow easy access to any data that is stored.

Size – The touchscreen should be 7 to 15 inches to ensure that the macaque has an interactive platform for behavioral experiments. The protective case for the screen should be snugly fitted to the screen size to guarantee that the macaque cannot remove or damage the screen. Any cage attachment points will have to match the Allentown cage wire thickness [4]. The liquid holder must be able to hold enough liquid for a day's volume worth of trials, or up to 100 mL [5].

- h. **Weight** – The touchscreen portion of the project must be able to be moved easily by the person removing it from inside of the cage. The average person can easily move 15 pounds [6], so that is our weight constraint of the touchscreen portion. Most 12 inch touchscreens weigh around 3 pounds [7], allowing the case to weigh 12 pounds. The component box will not need to be moved as often so it can weigh up to 25 pounds. This will include the stand, case and components.
- i. **Materials** – The project will need a touchscreen that interacts with the macaque. The touchscreen will need a protective case that can handle small impacts, as well as being waterproof. The most likely material for the case will be aluminum because it is easy to machine and not toxic to the macaque. The project will also need cable management. This will be some sort of polypropylene or adjacent tubing that keeps liquid and tampering failures from happening. The electronics portion will include a peristaltic pump which will dispense the liquid. It will also need wiring, a microcontroller, power supply, and data storage. These will be stored in a component box that is nonconductive such as PLA.
- j. **Aesthetics, Appearance, and Finish** – There should be no exposed circuitry. All edges should be beveled to ensure safety. The touch screen should be unobstructed to allow for maximum interaction with the subject. All components that are within urine range should be covered or have a waterproof coating. Visually it should be pleasing but looks are not a priority.

2. Production Characteristics

- a. **Quantity**- Client requested one prototype initially. If time permitted, more prototypes may be useful for the client. Making an easily replicable design would be highly desirable as well. The device should be able to move to different systems and easily detachable.
- b. **Target Product Cost**- There is only one product similar pertaining to our client's needs; however, it is an expensive and non-adaptable product. Our goal is to create a product using our budget, roughly \$5,000, to create a more inexpensive and reusable device.

3. Miscellaneous

- a. **Standards and Specifications** – IEC 60601 is an international standard regarding electrical safety for devices which could be used in a lab setting. Compliance with this standard is crucial to ensure the safety of the primates. Another standard we need to fall under is the Animal Welfare Act (AWA), specifically title 9 section 3.89. We need to ensure that our device is secured along with giving enough liquid to the primates. As outlined in the requirements, all nonhuman primates must be given water every 12-24 hours. 9 CFR [1] §3.75 Housing facilities,

general also applies: in particular, the device must be “free of excessive rust” and “jagged edges or sharp points that might injure the animals.” The device should also be able to be cleaned [8].

- b. **Customer** – David J. Herzfeld, a new professor in the Department of Neuroscience at UW–Madison. Prof. Herzfeld runs a systems neuroscience lab (<https://herzfeldlab.neuro.wisc.edu/>) in WIMR using a combination of animal behavioral experiments and computational modeling. Prof. Herzfeld hopes to use Primate Portal to run behavioral experiments with macaque monkeys.
- c. **Patient-related concerns** – The primates are water controlled and tend to urinate quite a lot; thus, the product must be able to withstand urination. The primates are also highly intelligent and are about the size of a toddler, so the screen should withstand shattering. The device should not have any sharp edges or wires exposed to ensure that the monkey cannot injure itself while using it. The device should have a failure mode and a way to notify the researcher if the device runs a trial in an unintended way (i.e., trains the monkey to do an unintended thing) so that the researcher can halt the experiment.
- d. **Competition** – While several in-cage primate training systems have been developed and published in the literature, the only commercially available competitor is Thomas RECORDING’s InCage Training System (ICTS) (<https://www.thomasrecording.com/thomas-incage-training-system-icts>). The Thomas ICTS is cage-mountable, with an 8-inch shock- and waterproof touchscreen and protection of internals from water and dirt. It is also possible to connect external devices like a video camera or a loudspeaker to the microprocessor and wirelessly control the behavioral paradigm and receive data. However, the Thomas ICTS has little capacity for extensibility in software and is prohibitively expensive, costing roughly \$100,000 (as informed by client).

References:

- [1] Intertek, “IEC 61010 – Safety requirements for electrical equipment for measurement, control, and laboratory use,” *Intertek*, 2025. [Online]. Available: <https://www.intertek.com/medical/iec-61010/>. [Accessed: 18-Sep-2025].
- [2] International Electrotechnical Commission, *IEC 61010-1:2010, Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements*, 3rd ed., Geneva, Switzerland: IEC, 2010. [Online]. Available: <https://webstore.iec.ch/en/publication/4279>. [Accessed: 18-Sep-2025].
- [3] U.S. Department of Agriculture, “9 CFR Part 3, Subpart D – Specifications for the Humane Handling, Care, Treatment, and Transportation of Nonhuman Primates,” *Electronic Code of Federal Regulations*, 1991. [Online]. Available: <https://www.ecfr.gov/current/title-9/chapter-I/subchapter-A/part-3/subpart-D>. [Accessed: 18-Sep-2025].
- [4] Allentown, Inc., “Large animal housing – Primate,” *Allentown, Inc.*, 2025. [Online]. Available: <https://www.allentowninc.com/large-animal-housing/primate/>. [Accessed: 18-Sep-2025].
- [5] University Committee on Animal Resources, “Policy on Macaque Food and Water Restriction,” *University of Rochester Medical Center*, 2016. [Online]. Available: <https://www.urmc.rochester.edu/medialibraries/urmcmedia/ucar/policies/documents/macaquefoodandwaterrestriction.pdf>. [Accessed: 18-Sep-2025].
- [6] L. J. Capitanio and S. J. Emborg, “Contributions of non-human primates to neuroscience research,” *Lancet Neurology*, vol. 17, no. 12, pp. 1129–1140, Dec. 2018. [Online]. Available: <https://pubmed.ncbi.nlm.nih.gov/29708048/>. [Accessed: 18-Sep-2025].
- [7] Beetrionics, “12-inch touchscreen monitor,” *Beetrionics*, 2025. [Online]. Available: <https://www.beetrionics.com/12-inch-touchscreen>. [Accessed: 18-Sep-2025].
- [8] Legal Information Institute, “9 CFR § 3.89 – Feeding,” *Cornell Law School*, 2025. [Online]. Available: <https://www.law.cornell.edu/cfr/text/9/3.89>. [Accessed: 18-Sep-2025].

B. Budget

Item	Description	Manufacturer	Mfr Pt#	Vendor	Vendor Cat#	Date	QTY	Cost Each	Total	Link
Electronics										
Raspberry Pi Model 3 B+	Advanced Raspberry Pi used to send out signals for motor controller	N/A	SC0073	UW Makerspace	SC0073	9/15/2025	1	\$45.00	\$45.00	https://www.raspberrypi.com/products/raspberry-pi-3-model-b-plus/
Wiring	Wiring to connect Raspberry Pi	N/A	N/A	UW Makerspace	N/A	9/22/2025	1	\$1.00	\$1.00	
Micro SD	Store Research data for researchers	N/A	N/A	UW Makerspace	N/A	9/15/2025	1	\$4.00	\$4.00	
Motor Controller	Connects to Raspberry Pi to initiate pump	Hiletgo	3-01-833	Amazon	3-01-833	9/22/2025	1	\$10.99	\$10.99	https://www.amazon.com/dp/B00WWSN98DC?ref=ppx_vo2ov_dt_b_fed_asin_title
Mechanical										
A300BX-S Pump	Pump to push fluids	Anko	A3028X-300-S	Anko	A3028X-300-S	9/15/2025	1	Gifted	\$0.00	ANKO A300BX-S OEM Peristaltic Pump Serial Control Brushless DC Models to 1700 mL/min
								TOTAL:	\$60.99	

C. Hardware – Software Intergration Code

```
import RPi.GPIO as GPIO #type: ignore
import time

# Set pin numbers
```

BME Design: 200, 201, 300, 301, 400 and 402

```
RPWM = 18    # PWM-capable physical 12 - purple
LPWM = 19    # PWM-capable (or 13) - physical 35 - brown
REN  = 23    # physical 16 - yellow
LEN  = 24    # physical 18 - blue

# Set the frequency we run the PWM wave at
F_PWM = 20000 # 20 kHz to reduce audible whine

# Set the board layout and warnings
GPIO.setmode(GPIO.BCM)
GPIO.setwarnings(False)

# Set the 4 pins we are using to output pins
GPIO.setup(REN, GPIO.OUT)
GPIO.setup(LLEN, GPIO.OUT)
GPIO.setup(RPWM, GPIO.OUT)
GPIO.setup(LPWM, GPIO.OUT)

# Start the PWM signals with 0% duty
forward_pwm = GPIO.PWM(RPWM, F_PWM)
reverse_pwm = GPIO.PWM(LPWM, F_PWM)
forward_pwm.start(0)
reverse_pwm.start(0)

# Set the

##### CHECK FUNCTIONS HERE AS THEY LOOK SOMEWHAT INCORRECT (FORWARD AND REVERSE MAY BE FLIPPED)
def forward(duty):    # duty: 0..100
    forward_pwm.ChangeDutyCycle(0)
    reverse_pwm.ChangeDutyCycle(max(0, min(100, duty)))

def reverse(duty):
    forward_pwm.ChangeDutyCycle(0)
    reverse_pwm.ChangeDutyCycle(max(0, min(100, duty)))

def coast():
    forward_pwm.ChangeDutyCycle(0)
    reverse_pwm.ChangeDutyCycle(0)
```