Integrative Summary

Improving the Malaria Microscopy Process in Rural Nigeria

ESC204
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Visual Abstract

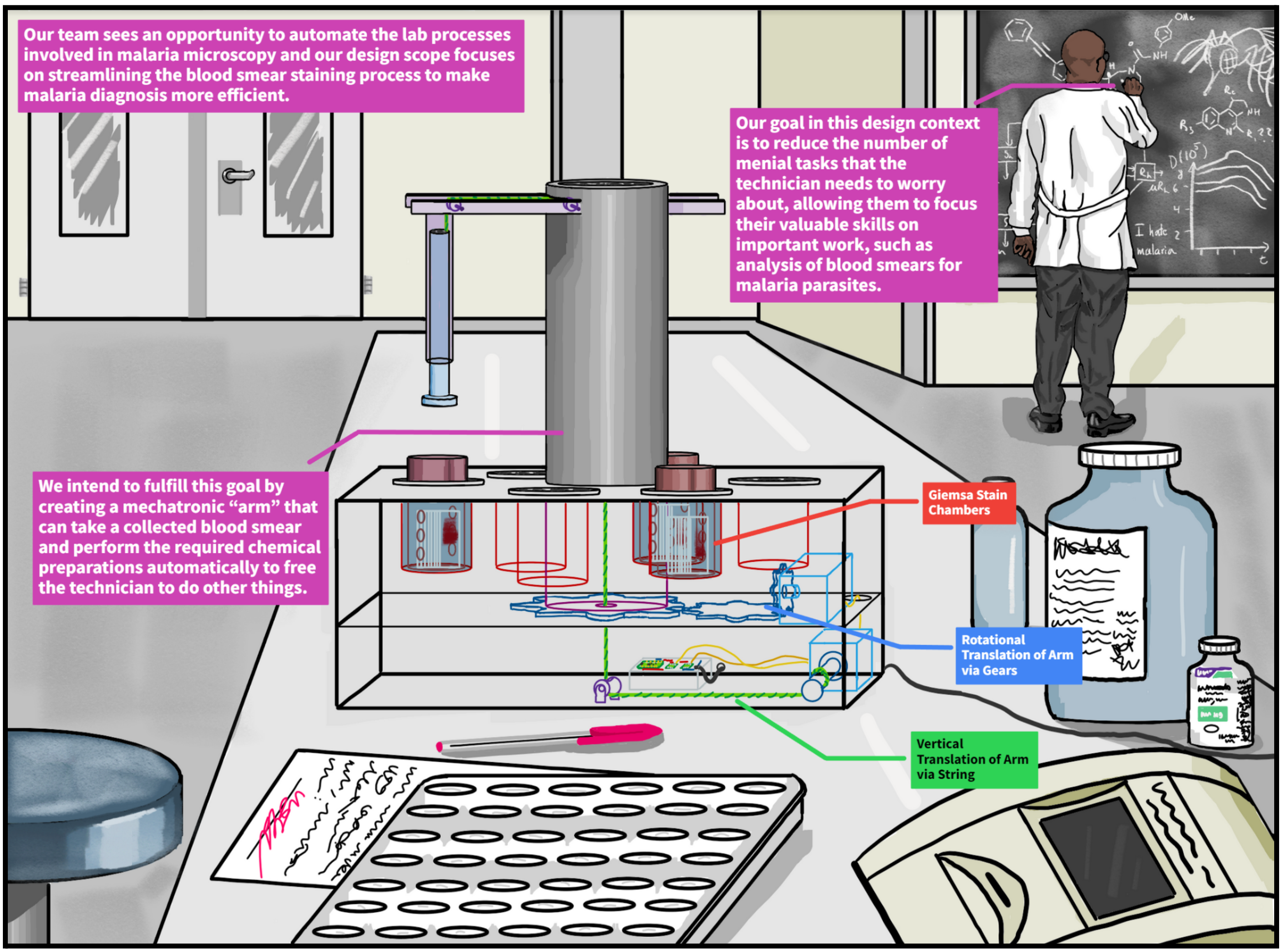

Table of Contents

Section 0. Summary of Revisions

Change	Reasoning
Updated section 3 with new artifacts and folder organizations.	There were some inconsistencies with folder organization from DD1 and we had to add many new artifacts from phase 2.
Updated value proposition.	We received some feedback about our value proposition and approaches being unclear from DD1, so we wanted to elaborate and better explain ourselves for DD2.
Updated requirements model discussion.	We received some feedback about how we could improve our discussion of our requirements model, so added some discussion on the requirements we chose.
Moved the timeline from DD1 to the section 2.4 and added a comparison between our planned timeline and our actual timeline.	The timeline was part of the required discussion for the statement of collaboration and our old timeline was outdated anyway. Thus, it made more sense to move it from the summary of design activities to the statement of collaboration.
Generally edited DD1 content.	The content was the same but we made some edits to improve concision, clarity, and tense (so that the content from DD1 and DD2 would flow together better).
Added the new sections from DD2.	The visual abstract can be found above, our phase 2 design activities can be found in section 1.4, the timeline can be found in section 2.4, and phase 2 artifacts can be found in section 3.4

Section 1. Summary Of Design Activities

Section 1.1. Design Context: Malaria in Nigeria

The challenge we were presented with is the issue of malaria in Nigeria. Especially in rural areas of Nigeria, malaria is an epidemic that costs hundreds of thousands of lives each year and has greatly stunted the economic development of the country [1, 2]. Malaria is a deadly disease that is primarily transmitted through mosquito bites and testing for malaria can be done through rapid diagnostic tests (RDTs) or blood smear microscopy [3]. RDTs generally have low accuracy but can be inexpensive and fast while microscopy procedures have high accuracy but take more resources and patients must go to the labs themselves. The opportunity is to improve the malaria testing procedures in Nigeria to better detect malaria cases and treat potential victims.

Our team built our interpretation of the opportunity space by conducting secondary research, attending the Q & A with the opportunity champion, and determining how our values complement the space. One issue that the opportunity champion stressed was the availability of RDTs in rural regions in Nigeria. Through secondary research (/02 Research/RDT Market Research), we discovered that low supply of RDTs is due to a mix of low demand cost, and supply side issues [5]. Another issue we recognized is the challenge of helping technicians keep track of diagnostic processes and process blood smears faster [6], which would both benefit from a mechatronic solution. Conducting research on the various lab systems (/02 Research/Microscope, hematology analyzer, chemistry analyzer, urinalysis machine, Glucometer and /02 Research/Joaquin Research Weekend 21-22) helped us scope down our opportunity space to focus on automation of the testing process.

With this context space in mind, our team analyzed the relevant stakeholders.

Primary Stakeholders	
Potential Malaria Victims	At the most granular level, these stakeholders are the primary beneficiaries of any improvement to malaria testing in Nigeria. As they are physically afflicted with the disease, it is important to consider their position and considerations when designing a solution.
Technicians	These vital workers operate and maintain the standard for malaria testing, and must be informed/trained for any updated procedures.
Doctors researching and treating malaria	Since our solution is within the medical/engineering sphere, our design must be backed by evidence and experts who know the in-depth mechanics of malaria and its treatment.
Nigerian Government/Healthcare Facilities	Considering that our solution will be something physical, cost and several implementation factors must be considered, which are directly governed by these two institutions.

eHealth Africa	As an NGO whose goal is to provide care to underserved Nigerian communities, our solution aligns with their goals.
Our Team	Our team is the one designing the solution for our scoped opportunity and who's learning are correlated with the performance of the final design.

Original: (/03 Artifacts/Meeting Artifacts/Value Proposition Discussions/Context Scope)

Value Proposition: (/03 Artifacts/Meeting Artifacts/Full_Value_Proposition)

The opportunity statement given by ESC204 outlines three specific methods when considering how to add value towards the treatment of malaria in Nigeria. These included:

1. Increasing availability of RDTs in rural communities.
2. Improving the turnover time for tests via enhanced coordination methods.
3. Improving efficiency of test procedures and lab processes.

Rather than choosing one specific challenge outlined above and potentially limiting our initial divergence space, our team chose tackling these three challenges holistically as adding value. Each of these challenges are clear in their existence and a solution that addresses any of them would certainly work to the overall betterment of the malaria treatment in Nigeria. It is then better to account for each of these three challenges such that potential solutions could address more than one of these during development. Furthermore, both secondary research and direct conversation with the Opportunity champions supported the notion that design spaces need not be limited to just one line of thinking. Therefore, our group aims to add value to our outlined stakeholders by aiming to tackle any of these three challenges.

Section 1.2. Approaches to Providing Value: Stakeholder Pains and Gains

Given our value proposition, we framed the opportunity into 3 approaches: automating lab processes, prevention, and promoting awareness (/03 Artifacts/Meeting Artifacts/Value Proposition Discussions/Concept Scope). The summary of our discussions can be found in (/01 Meeting Agenda and Minutes/DD1 Or Phase 1/Jan. 31 2023).

Our first approach considered the idea of automating lab procedures as a means for technicians to save time, as this would directly address the third key challenge outlined in the opportunity statement. In doing so, technicians would instead be able to spend more time working on complex tasks that require more expertise and cannot be automated, improving the overall efficiency of the testing process. Furthermore, coordinating diagnostic tests could become much simpler if these processes were to be automated by a central system.

Our second approach, which was framed through the lens of malaria prevention, was designed to reduce the overall number of malaria cases in Nigeria. The number of tests that need to be processed by labs would also decrease, as fewer people would need to be tested for the disease. This would decrease the strain placed on lab technicians, as there would be fewer tests to process. Additionally, it would lower the total amount of malaria treatment resources required, as fewer people would be infected with the disease. However, there is an issue with this approach, which is that it is difficult to tell if a prevention method is working or not due to the lack of data concerning malaria infection in Nigeria. There is a need for accurate and up-to-date information on the incidence of malaria in the country, in order to properly evaluate the effectiveness of prevention methods. Ultimately, we decided to focus on a different approach.

Our third approach aims to tackle the first challenge outlined in the challenge statement, which is to increase awareness about the importance of malaria testing. Currently, many Nigerian citizens in rural areas lack proper education about malaria prevention and treatment, leading to increased cases, decreased testing, and wasted resources (/02 Research/Champion_Meeting). By promoting greater awareness about malaria and the benefits of testing, we can generate greater demand for Rapid Diagnostic Tests (RDTs) and encourage more people to undergo in-lab testing. This increased uptake of testing will lead to more accurate data on malaria infection, enabling more targeted and effective treatment and prevention strategies. Our research on the RDT market [6] indicates that increasing awareness about malaria testing is a key factor in improving the uptake of RDTs. Therefore, by focusing on this approach, we can make a significant impact on malaria prevention efforts, ultimately improving the wellbeing of the population.

Requirements Model

Objectives:	Metrics:	Criteria:	Constraints:
Reduce time taken in the overall lab process	Average time / task (min/task)	Lower better	Must be at least as fast
Reduce number of tasks requiring technician	Number of tasks	Lower better	Must not be more than current
Increase accuracy of diagnosis	% accuracy [(#correct diagnosis / total # of tests) x 100%]	Higher better	Must be at least the same as current
Reduce OpEx (Operation Expenditure)	Money/Test (₦/Test)	Lower better	N/A
Reduce CapEx (Capital Expenditure)	Money (₦)	Lower better	N/A
Usability	Time required to master operation (hours)	Lower better	N/A

₦ = Nigerian Naira, the standard currency in Nigeria

The goal of the opportunity is to improve some aspect of malaria testing in rural Nigeria. As our group chose to improve malaria microscopy through automating chemical processing of blood smears, our primary requirements should target increasing efficiency of testing in the lab. We decided to quantify the vague idea of efficiency through measuring the time taken to process samples ("reduce time taken in the overall lab process) and the amount of work required from technicians. We chose to include both requirements since increased efficiency in the lab could originate from both reduced time costs for testing procedures as well as freeing up technicians.

Following these two requirements, we also added a requirement for increasing the accuracy of the diagnosis with the constraint that the accuracy must be at least the same as it is now. We believe that it is not ethical for our team to make the choice between sacrificing the quality of life-changing malaria tests and improving testing efficiency. Thus, this requirement is necessary to ensure our designs take no shortcuts in sacrificing quality for quantity.

Our OpEx and CapEx requirements stem from our champion meeting (/02 Research/Champion_Meeting) where he mentioned that cost is a primary barrier to new technologies that could already improve lab procedures. It is useless for us to create some complicated machine to automate everything but be too expensive for any lab in rural Nigeria to afford. Thus, requirements that limit the implementation and operation costs of our design are necessary. However, since we could not obtain information on the exact budget the labs have, we can only rely on vague criteria of trying to lower the cost as much as possible.

Finally, we want our design to be intuitive and easy to use. Our goal is to reduce the complexity of the technicians' work as much as possible. Having a design that is incredibly difficult to use opposes that goal since technicians will require more training and waste more time operating the machine. Furthermore, complexity may discourage adoption of the design.

Section 1.3. Conceptual Design: Automation of Malaria Microscopy

Section 1.3.1. High-Level Description

Our design concept is a compact device to automate the chemical processing of the blood smears required for microscopy procedures. Before a blood smear taken from a patient can be analyzed for malaria, technicians must put the blood smear through an arduous chemical dipping process that takes around 25 minutes per sample [6]. Using the rapid (but expensive) method, the blood smear must be fixed for 5 seconds and left to dry for 2 mins, the thick smear must be dehemoglobinized in water for 5 seconds, the entire smear must be immersed in 10% giemsa stain for 20 minutes, the slide must then be rinsed for 30 seconds in water, and finally, the smear must be air dried before analysis [7]. Since each sample must soak in different chemicals/dry for precise amounts of time, it is difficult for technicians to keep track of many samples at once, causing them to waste vast amounts of time doing a relatively menial task while introducing the potential for human error in processing the slides.

Our design concept aims to eliminate this inefficiency by automating the chemical dipping process using a mechatronic "arm" controlled by custom software. With our design, a technician would only have to collect the blood smear from the patient and put it in a tray. Furthermore, unlike humans, software is able to easily time multiple batches of slides, allowing a large number of blood smears to be processed continuously. The number of slides per batch will be based on the amount of time required for each batch of slides to finish the process and the amount of time required for the technician to collect each slide. This design would then allow the technician to focus only on the collection and analysis of blood smears with minimal time lost to menial chemical preparation.

Section 1.3.2. Summary of Design Process Reaching Design Concept

Our design process before reaching our final design concept involved precisely framing the situation and exploring multiple pathways before diverging and converging on an approach we liked. We began our design process by trying to understand the situation. With the baseline information provided in the opportunity statements, we conducted extensive research on topics ranging from climate conditions in Nigeria to global standards on malaria research and treatment (/02 Research/). This research helped us to gain a much deeper grasp of the situation that helped us to begin defining the context that we are working in with this opportunity.

We moved forward with our design process by working through the context-approach-concept framework (/03 Artifacts/Value Proposition Discussions/Approach_Scope.png and Context_Scope.png). With our research, we were able to define the relevant stakeholders to the opportunity and analyze what their "pains and gains" were. Understanding the struggles of the community and how they could benefit naturally led to the approach step, where we defined three primary ways we could provide value to the situation: improve microscopy testing, promote awareness, and prevent malaria infections. For each general approach, we briefly came up with some ideas to explore what specific approaches and design concepts could look like to better understand each general approach and make sure they were scoped at a level that allowed for creativity, but also encouraged straightforward designs that tackle a specific challenge faced by the stakeholders. After further research, discussions with TAs, discussions with Praxis III professors, and the meeting with our opportunity champion, we decided to converge to the general approach of improving the microscopy process. We believe that this is the best area for our team to work in because we have concrete research that define challenges that stakeholders experience with the process, international standards on microscopy related processes to guide our design work, and unlike prevention mechanisms, potential designs for microscopy automation processes have not been extensively researched.

With a general approach defined and some more specific approaches to improving microscopy in mind, we felt that our scope was narrow enough to define a requirements model with concrete objectives that could effectively guide our design process moving forward. Using our research and information from the opportunity champions, we defined a set of objectives that specifically targeted the development of design concepts that aim to improve the microscopy process in some way (see requirements model table). This led to our first round of diverging where we used the lotus blossom technique to come up with potential design concepts for each of the three specific approaches to improving the microscopy process: improving the blood collection process, chemical processing of the blood smears, and analysis of the blood smears (/03 Artifacts/Meeting Artifacts/Diverging Solutions/Lotus_Blossom.jpg).

The design concept we considered for improving the blood collection process involved having a machine pierce the user's finger to draw blood, which would then be placed inside a microscope slide. However, this could present ethical issues as having a machine automatically impale the user's finger may be both intimidating and dangerous. In addition, drawing blood is a task that does not require much effort, rendering the idea inefficient given how much it would cost to replace the relatively small amount of work.

In another concept, we considered a solution for improving the procedure for preparing a microscope slide that contains a blood sample [7]. Slides must be submerged in several chemicals for various amounts of time prior to being examined on a microscope [6]. This procedure could be automated by a robotic arm that submerges one or multiple slides into each of the liquids. Given our set of skills and the required mechatronics component, we deduced that this would be fairly simple and ideal for us to implement.

Our last concept was a system that could automatically determine if a blood sample contains malaria. This involved utilizing the microscope's camera to capture photos of a blood sample and employing a machine learning model to detect traces of malaria. However, research on the performance of previously existing models indicated that they were not highly accurate in detecting traces of malaria [8], and accuracy is crucial in diagnosing contagious illnesses. The lack of accuracy in a previously implemented model also implied that it would not be feasible for us, as undergraduate students, to create an accurate machine learning model. A model alone would also not fulfill the requirement of a mechatronics component. Furthermore, the opportunity champion stated that camera-based microscopes already exist but are not used due to large costs, which violates our cost requirement (/02 Research/Champion_Meeting.pdf).

Based on the design concepts that were considered, we decided that working on automating the chemical processing of the blood smears would be the most suitable route.

Section 1.4. High-Fidelity Prototype: Chemical Staining Arm (C.S.A)

Section 1.4.1. High-Fidelity Design

Diagram of system architecture can be found:
03/Artifacts/Prototyping Artifacts/Planning and CAD/system_architecture_final.pdf

Our high-fidelity design describes a central mechatronic arm with a surrounding circular tray system that contains beakers of chemicals that are required for the chemical processing of the blood smear. The technician will place prepared blood smears into open-weave baskets made of inert materials and place the basket into a waiting area in the circular tray around the arm. The baskets will be sealed with a lid that has a magnet attached to the middle. Upon detecting a basket in the waiting area, the mechatronic arm will lower and "grab" the lid by activating an electromagnet at the tip of the arm. The arm will then move up, rotate to move the basket to be above the chemical it needs to be in, lower the basket in, and finally disable the electromagnet. Once finished moving the basket, the arm will be free to move other baskets around to take them through the chemical process. The timing for each batch of blood smears and the logic of when to start each batch (to make sure there is no conflict between 2 batches requiring the same chemical) will be done with a microcontroller that will send instructions to the vertical and rotational translation mechanisms for the arms.

We chose a batch system for processing the slides rather than processing each slide individually for two main reasons. First, using a basket to hold the slides allows us to attach a basket lid that will close off the chemical containers when slides are placed in to reduce the evaporation of expensive chemicals (reducing cost) and reduces the potential for contamination. Second, processing small batches of slides at once will likely be more efficient than processing a large batch of slides or individual slides. Preparing and analyzing smears takes time, so processing a large number of slides at once would result in wasted time when the machine is waiting for the technician to get slides ready and when it gives the technicians too many slides at once. Processing slides individually is also inefficient since the number of arm actions required would be several times higher. Thus, small batches of slides is the most efficient option and the exact batch size will depend on rate limiting steps in the chemical process, time required for the technician to prepare blood samples, and time required for analysis.

Section 1.4.2. Parts to be Prototyped

The prototype for our design concept will be a “scaled down” model of the entire system. The goal of our prototyping is to verify our design is sound in practice and to model real life interactions to make sure the design is meeting stakeholder needs. Thus, rather than build the entire machine, we will be making a prototype of the design that is smaller, uses substitute materials to proxy real equipment, and simpler in its operation (conducts a cut down version of the actual process with fewer chemicals), which is sufficient to demonstrate the idea will work and conduct proxy tests to ensure it meets our requirements.

Section 1.4.3 Required MaterialsMaterials and Equipment Required

Material	**Usage**	**Comment**
PLA filament	Used for 3D printing components of prototypes such as the basket that will hold the blood smears.	PLA filament is very inert to general chemicals, including methanol which is used in the chemical processing. [6] Therefore, a good choice of material to create the slide basket.
Wood	Used for creating crankshaft, circular tray for chemical containers, gears, etc.	As this wood is just used for prototyping purposes, the quality is not very important. However, the wood used must be structurally sound for components like the crankshaft since it must be able to withstand a certain amount of force without straining.
Metal wires/string	Used to provide support to the arm.	

Stepper Motors	Used to turn the crankshaft and to rotate the arm.	Must be strong enough to deliver the torque necessary to turn the crankshaft and arm.
Magnets	Will be attached to the lids of slide baskets to attach baskets to arm.	Magnetic force between the magnets and electromagnet must be strong enough to hold the basket with the slides.
Microcontroller	Used to process the logic and send instructions to the mechatronic arm.	Essential element for circuitry

The motors we require for our current design need to be able to provide sufficient torque to move the arm and we need to be able to precisely control them. Based on our experience in lab six, we believe that the DC motor and the stepper motor may be suitable options for what we need but further experimentation with the motors is required to fully understand them and ensure they meet our requirements (/03 Artifacts/Studio Artifacts/DC_Motor.mov).

Section 1.4.4 Prototyping Report

Since the purpose of our prototyping was to ensure our design concept would work in practice and to work out unforeseen challenges, we believed it would be more valuable to first prototype each subcomponent by itself before system integration to save time and allow for more adaptability to respond to design challenges. These subcomponents were all designed in tandem since they often impacted the design of each other. Of course, having a large-scale fully integrated prototype would be valuable for testing functionality and assessing fulfillment of our requirements so we allocated some time towards the end of the course for both system integration and extra time in case something goes off plan. The following sections will describe functionality, design process, and prototyping results of our subcomponents and final prototype.

Section 1.4.4.1 The Slide Container

The slide container fulfills a very simple role, in which it must house the stained slides while also allowing them to be submerged by liquid chemicals. They must also be easily transportable by the arm mechanism and uniform across the six stations, Thus, we designed cylindrical container with two sets of holes on the side so that liquid may flow easily and one hole at the bottom so that the water does not condense underneath the container and cause buoyancy to obstruct/delay placement. Furthermore, the top surface contains a compartment that holds a magnet, which attaches to the arm mechanism via the BAM system.

Section 1.4.4.2 The Beaker Attachment Mechanism (BAM)

The BAM is responsible for the attachment between the arm and the beakers such that the slides can be reliably transported across the system - hence unification. In its early stages of divergence, our team understood the innate difficulty of a purely mechanical solution due to the required strength and precision to pick up a container.

Originally, we planned to use an electromagnet, who's magnetism could be controlled by varying a current using a microcontroller. This idea worked well in theory, as it fulfilled all of the necessary requirements for the BAM, and we began experimenting with various electromagnets (/03 Artifacts/Studio Artifacts/Planning and CAD/Electromagnet/electromagnet_test_1.mp4) to test the amount of force required for our design. Unfortunately, our results from testing these electromagnets yielded poor results, as the sheer weight of the electromagnet was too large of a detriment to justify its use. This sentiment was further supported by a consultation with Micah Stickel, our current Electromagnetism professor and expert in electromagnetics (/03 Artifacts/Studio Artifacts/Planning and CAD/Electromagnet/em_prof_meeting).

Our team instead employed a regular magnet for this mechanism, where a magnet would be attached to the arm and each beaker. A simple magnet carried all of the relevant benefits of the previously proposed electromagnet, with the only caveat being that its magnetism could not be controlled. However, when weighed against the sheer volume and weight decrease that this solution would bring, it was clear that it was a price worth paying. To rectify the constant magnetic field, we took advantage of the stepper motor's 200-degree precision to forcefully rotate the arm with the container secured to "slide" the magnet off the container(/03 Artifacts/Studio Artifacts/Testing/Mechanical Tests/magnet_detatchement_test.mp4).

Section 1.4.4.3 The Rotational Translation System (RTS)

The rotational translation system is responsible for rotating the arm, both for moving slide containers to appropriate locations and for breaking off the magnetic attachment mechanism. The initial design for this subsystem was to house it in the box containing the beakers with a gear system attached to a stepper motor to control the rotation of the arm (03 Artifacts/Prototyping Artifacts/Planning and CAD/box_sketches_2.png). Although the design seemed simple during our initial planning, we faced several challenges when we began CADing and building. First, this system needed to interact well with the VTS. This meant that the RTS needed to rotate the arm but not impact the functionality of the VTS (ex. simply spinning the arm may end up with tangled wires and cords that breaks the VTS). This was resolved by adding a hole in the bottom of the central tube which allows for VTS components to be inserted through the hollow tube and remain still as the surrounding tube rotates. Second, the gears need to be held in place. The gears needed to remain still when rotating, avoid the beakers above, and interact with a motor. We initially used a dowel to hold the gears, but quickly realized the friction between the walls and the gears greatly resisted spin, so we changed to washers that lifted the gear slightly to decrease surface area (03 Artifacts/Prototyping Artifacts/Planning and CAD/washers.png). Initially we were also concerned about the precision/variation of the motor, so we designed a geneva gear to move the arm in quantized steps. However, upon testing, we found the stepper motors were sufficiently precise for our prototype, so we discarded the geneva gear. If required in future prototypes, the geneva gear can be used to precisely move the arm.

The RTS were fully designed in CAD before we began our manufacturing process(03 Artifacts/Prototyping Artifacts/Planning and CAD/CAD Timelapses). Due to inexperience with

CAD and CAM, several design and manufacturing iterations were required before the system worked. Aside from the relatively trivial issues like bad tolerance estimations, we had issues with manufacturing our prototype the way we designed it (ex. supports in 3D prints interfering with design, material being thinner/weaker than intended, 03 Artifacts/Prototyping Artifacts/Manufacturing and Construction/bad_supports) and our designs were often flawed (ex. gear not turning very well at 90 degrees). This required us to go back, brainstorm ways to resolve the challenges, and try again multiple times before it finally worked (ex. beveling gears to improve contact).

In the end, we were able to build a functional rotational system connected to a motor. Our testing of this prototype shows that a basic motor and gear system has the power and precision required to move containers around as well as disengage the beaker attachment mechanism. An early artifact demonstrating both the RTS and VTS can be found here: 03/Artifacts/Prototyping Artifacts/Testing/Mechanical Tests. An artifact demonstrating functionality later on will be referenced in a later section.

Section 1.4.4.5 The Vertical Translation System (VTS)

This system serves to control the vertical translation of the arm as it moves during the staining process. More specifically, it will move the arm downward such that it can make contact with a specific beaker, and move up in tandem with the RTS (detailed previously) to detach from beakers.

Initially, this mechanism was intended to be housed within the main cylindrical trunk of the design, where a crankshaft would push the trunk (and thereby the attached arm) up and down via a gear system. While this simple design was sound on paper, we were quick to realize its shaky feasibility once we outlined the specific dimensions. On top of the demanding number density of components that would need to be kept within the trunk, the diameter of the crankshaft itself would need to be much larger than the diameter of the trunk. This is because of the minimum range of height that the VTS must translate in order to fulfill its purpose, which was greater than a reasonable diameter for the trunk(03 Artifacts/Prototyping Artifacts/Planning and CAD/VTS_piston.png).

To remedy this, our team began diverging again (03 Artifacts/Prototyping Artifacts/Planning and CAD/side_arm_plan.png), where we converged on a pulley system inspired by one of our previous team meetings (01 Meeting Agenda and Minutes/DD1 or Phase 1/ Feb. 17 2023 Meeting Recording.mp4). Since the structure of the overall design was relatively linear, we realized that a simple string powered by a stepper motor could be run through the trunk and into the arm without any disturbance. Furthermore, it would not collide with the mechanisms of the RTS, as the string would be sent through the one area that would not be affected by the rotation of the cylindrical trunk: the center.

With this general idea in mind, the components were modeled in CAD software to simulate their physical validity. This involved a spool that would attach directly to the stepper motor and hold one end of the string, three pulleys to guide the string and eliminate friction throughout its path. Similar to the construction of the RTS, there were several trivial setbacks with the actual manufacturing that caused us to reiterate several designs. However, no component's design was completely overhauled, and we were able to completely build and test the functionality of the VTS, as well as its simultaneous usage with the rest of the design.

Section 1.4.4.6 Hardware Systems

The main aspects of the Hardware System is the manipulation of the VTS and RTS systems using two Stepper Motors, controlled by a Raspberry Pi Pico. Using skills developed over Studio B Lab 5 and 6, we were able to design a circuit that would connect the Raspberry Pi to the motors and allow them to be manipulated. We also used components that were not presented in the Lab material but were instead recommended to us by a peer from a different Praxis Team, and independently researched.

Stepper Motors use four electromagnets to create a rotational motion around the axle (/03 Artifacts/Studio Artifacts/Electronic Components/stepper_motor.gif). Since there are four electromagnets, these motors can be extremely precise, with 200 distinct states around the whole circular arc. We chose to use these motors due to this exact property, since the RTS and VTS required exact movement. By 3D printing a gear (/03 Artifacts/Studio Artifacts/Electronic Components/prototype_motor_gear.png) and a spool to integrate the motors with the two major subsystems, we were able to create interaction between the electronic components and the mechanical ones.

To control the motors, with the Raspberry Pi, we used an A944 Stepper Motor Driver chip (/03 Artifacts/Studio Artifacts/Electronic Components/A4988.jpg), provided by MyFab, since other groups were having trouble with Stepper Motors and one of our peers recommended it to us. This driver was able to simplify the manipulation of the motors down to two pins, and handled the voltage stepping without requiring a separate component. With two chips, we were able to control both Stepper Motors with four pins total. In order to power our two Stepper Motors, we used a 12 volt power supply and a barrel to bread-board connector. Once the code was loaded onto the Raspberry Pi, we could begin testing each process separately and then together, which is described in Section 1.4.5. The full circuit in its completion can be found in: /03 Artifacts/Studio Artifacts/Electronic Components/prototype_2.5_complete_circuit.png.

Section 1.4.4.6 Software Systems

Software to control both the RTS and VTS were implemented on a Raspberry Pico. A summary of the logic can be found as a state diagram here: 03 Artifacts/Prototyping Artifacts/Software Components/code_state_diagram.png

A position variable, *pos*, was defined for the rotational location of the arm. As there are six different locations for the basket to be placed, *pos* would be set to various discrete values from 1 to 6 inclusive throughout the execution of the code. A function, *rotate()*, was implemented to incorporate rotational translation into the code. The function rotates the stepper motor to match an input position based on the initial value of *pos* and updates the value of pos to be equal to the initial position. The function also allows the arm to be rotated half of a discrete amount and back, as a "half rotation" is part of the procedure for disconnecting the basket from the arm.

Another position variable, *height*, was defined for the vertical position of the arm. The prototype was originally designed for the arm to be at multiple heights in order to allow the basket to be dipped halfway into water, as required at one stage of the slide processing procedure. However, this was replaced with the idea of simply filling the first water container halfway, which would in turn allow only half the slide to be submerged even if the arm were to be at its lowest level. For this reason, the code defines values of *height* at 1 and 5 to be "low" and "high". A function, *vt()*, was implemented in a manner similar to rotate in that it utilizes a stepper motor to adjust the height of the arm and updates the value of *height*.

The inclusion of the *rotate()* and *vt()* functions simplifies the implementation of the procedure outlined in Figure 2. Functions *pick_up()* and *let_go()* were defined using the *rotate()* and *vt()* functions to further simplify the implementation in the procedure functions.

A function for each step of the procedure was defined (eg. *load_meth()*, *meth_dry()*), in which the respective steps were simply implemented by utilizing unique sequential combinations of the functions *rotate()*, *vt()*, *pick_up()*, and *let_go()*. These functions were all included in another function, *procedure()*, in a particular order. In addition, to account for the time that it takes for the arm to move as needed, calls of the function *wait()* are inserted between the calls of each step's functions. This ensures that if, for example, the basket needs to be submerged in a specific substance for 5 seconds, the timer does not start until the basket has been placed into the substance. This was tested early on through the use of print statements (03 Artifacts/Prototyping Artifacts/Testing/Mechatronic Tests/code_state_testing_ITWORKS.mp4).

For the sake of readability of the code, several variables, including *pos* and *height*, were originally defined as global variables. However, the use of global variables is considered to be bad practice as it can result in unprecedented issues [9], especially when used in larger code files. For this reason, the global variables were replaced with local variables that were simply parameters for the functions that required them, and these functions would return updated values of these variables.

In order to test the code incrementally, a testing function was created to see if the motors were in fact moving, and then whether or not they were interacting with the mechanical parts, and then finally if they were moving the VTS and RTS as much as we wanted them to. This function was called *testing()* and contained parameters for which system you wanted to test.

Separating the code like this allowed for better debugging as the processes were simpler and one can easily see where in the code, or in the mechanics, the prototype fails.
All software versions can be found in 03 Artifacts/Prototyping Artifacts/Software Components/.

Section 1.4.4.7 Final prototype

Our prototyping culminated with successfully creating a functional version of our designed machine. Mechanically, our prototype is able to precisely rotate to any angle by going clockwise or counterclockwise, safely lift and transfer slide containers, and snap off the magnetic connection in a rotational motion. Our software is also able to control our motors and precisely carry out the chemical processing procedure on the slides.

On the mechatronics, we first had a test (/03 Artifacts/Prototyping Artifacts/Testing/Mechatronic Tests/Prototype_2.1_motor_integration_test.mp4) where the prototype's software was able to control the VTS and RTS. This involved rotating around and moving the BAM appendage up and down. This was an important milestone as previously the motors hadn't been integrating with the software previously. The next important test was a precise test where we programmed the arm to do a simple task of picking up a basket from one beaker, placing it down into a different beaker, and then detaching the BAM component (/Team 0106B/03 Artifacts/Prototyping Artifacts/Testing/Mechatronic Tests/prototype_2.1_pick_up and_place_ITWORKS). This test was the most important mechatronic test we conducted as it proves that our arm can lift and drop a basket, the most unbelievable part of the prototype.

Although we tested each subcomponent independently, we conducted additional testing after we finished integration to ensure everything performed the way we expected. Since we did not have access to actual lab materials and chemicals, we proxied a lab environment by filling our beakers with water and one container with glass (to simulate slides). We then picked and placed the container from a few slots to ensure the VTS and RTS systems worked and our magnetic attachment and arm were strong enough to lift, transport, and drop a container with slides. We also attempted to rotate the arm quickly with a container attached to make sure the container would not detach from the arm under rapid motion.

After those tests, we were confident that our prototype achieved the basic functionality we were looking for, so began testing to determine how well it meets our requirements. For the requirement "reduce the number of technician tasks", it is difficult to give a quantitative answer to how many tasks we have reduced. However, since our prototype only requires the technician to insert the slides and remove them once ready, automating all the chemical processing, we can confidently say we met that requirement.

In terms of CapEx, our fully assembled model only costs about $67 or ₦22797 (estimates based on budget tracker), which is significantly less than the average ₦600000 that each lab technician makes per year [11]. For OpEx, our prototype does not have any ongoing expenditures besides the cost for chemicals (which we attempted to reduce by adding lids to containers) and typical maintenance costs (which are low due to inexpensive parts). Thus, our prototyping thus far establishes that a functional product can be provided to the labs at an affordable cost.

It is difficult to determine if our prototype can increase the accuracy of diagnosis or reduce the total amount of time required because we have access to neither lab materials nor malaria samples. However, we conducted a proxy test where we simulated the chemical processing of one sample using both our prototype and manual labour. In between the chemical processing steps, we had the "technician" (a group member) do math problems (03 Artifacts/ Prototyping Artifacts/Testing/General Tests/ESC204ManualProxyTest.mp4). In the end, we found that the "technician" solved more problems when using our prototype rather than manually processing the samples due to both reduced time and distractions. While this proxy test is obviously not fully representative of a real-life situation, it shows that our prototype can improve the productivity of the technicians. Furthermore, the test was run with only one sample, while in reality, multiple samples could be processed at once, saving even more time. Thus, our proxy test shows that our prototype can provide productivity benefits to the lab.

Finally, we tested for usability. Our requirement is to minimize the amount of training time required for a technician to operate the machine as intended. To test this, we recruited a few of our peers from the same malaria opportunity, explained our prototype to them, and asked them to operate it while vocalizing their thoughts so we could discover any confusing aspects of the design. We chose peers with the same opportunity because in real-life, the technicians operating the machine are already familiar with the situation and chemical processing (03 Artifacts/ Prototyping Artifacts/Testing/General Tests/usability_test.mp4). From our testing, we determined that minimal training was required for a technician to operate the machine, mainly since there is very little for the technician to do. However, there were some issues that will be described below alongside potential future improvements to the design.

From our overall testing, we determined a few ways we could improve our design in the future. First, we currently lack signals indicating the state of the machine. Right now, technicians would not know when the machine is ready for a sample and when a sample is finished. This can be resolved by simply adding LEDs to indicate the state of the machine (ex. if a sample is finished, light up a green LED in the position). Second, we do not have any fallbacks in place in case something unexpected happens. In the event that something goes unexpectedly (ex. a technician did not fully screw something on), our machine would continue operating regardless of the situation, which may lead to further damages to the machine and the sample. Resolving this issue would require sensors to check if everything is operating correctly (ex. a weight sensor to check if a container was placed in a beaker correctly). A more mechatronic issue in the prototype is the inconsistency in the lowering process of the VTS, since the string in the arm gets caught sometimes when the motor provides slack. This can be fixed by creating a better housing component for the string itself within the arm, to reduce the amount of places it can get caught. Finally, we need to add some anti-slip mechanisms to our containers. In our usability tests, we saw subjects struggle to grip the smooth cylinder securely, which would be exacerbated if we used chemicals that wet the surface of the PLA. Adding a rough surface or changing the beaker shape to include edges (ex. an octagon) may help to resolve this issue.

Overall, while there is still a lot of work to do, our final prototype shows that our design is feasible functionally, can improve the productivity of technicians in the lab, is affordable by Nigerian labs, and can be operated easily.

Section 2. Statement of Collaboration

Section 2.1 Team Values and Strategy

Throughout the project, the team's main goal was to create a good prototype. To achieve this goal, the team expected every member to carry their weight and contribute to the project's success. We wanted our prototype to include fully integrated functionality of each subsystem to demonstrate the possibility that the prototype could be developed further.

The minutes of every meeting were meticulously recorded by Joaquin, ensuring that everyone was on the same page. All these meetings are summarized in the meeting minutes (01 Meeting Agenda and Minutes/DD1 Or Phase 1, 01 Meeting Agenda and Minutes/DD2 or Phase 2). Outside of meetings, the team conducted communication through Discord, which served as a platform for coordinating meeting times and locations. The team also used it for asking questions to the larger group and conducting fun team-building activities.

To promote team cohesion, the team played two games: the Google Ghost game and the 2018 hit game Among Us. Both were fun and engaging activities that allowed team members to laugh and lighten up among the chaos of our schedules and deadlines. Early on, we didn't fully know everyone in the group but competing in these smaller activities helped us get to know each other. While working on DD2, we occasionally took breaks to watch Gerry play Brawlhalla (03 Artifacts/Meeting Artifacts/Teamwork/teambondingDD2). This made the long hours working on DD2 together more bearable.

Section 2.2 Summary of Team Contributions

For the most part during DD1, all team contributions were done collaboratively. All of our framing, diverging, and converging were done as a group during team meetings or studios. If someone had an idea they came up with on their own, we would still discuss the idea as a group and often the modifications came from other team members with different perspectives.

The specific framing we decided on, automating lab logistics, was a group decision we made after debriefing the Champions meeting (01 Meeting Agenda and Minutes/DD1 Or Phase 1/Feb 3. 2023). We diverged possible solutions as a team and decided upon which concept we wanted to work on as a group (01 Meeting Agenda and Minutes/DD1 Or Phase 1/Feb 7. 2023).

Of course, there were tasks we needed to do individually in the interest of time efficiency. In our initial meeting (01 Meeting Agenda and Minutes/DD1 Or Phase 1/Jan 20. 2023), a lot of research questions were made. This was the first individual task we assigned ourselves. We split the research questions amongst ourselves and then discussed them during the next meeting (01 Meeting Agenda and Minutes/DD1 Or Phase 1/Jan 23. 2023).

The second set of tasks we split up to be individually worked on was this document, the Design Dossier Integrative Summary. A summary of these tasks and the way they were divided, both individually and collaboratively, is laid out in the Schedule and Responsibility tracker.

The team was split into working on different subsystems during DD2, with some team members focusing on coding and others focusing on CAD and building. We maintained team cohesion by frequently checking in on each others' progress informally through discord and showing each other our progress during the studio (00 General Resources/Schedule/Response/Budget).

Section 2.3 Analysis of Teamwork

The team made most decisions collaboratively during meetings for DD1. We started by having team discussions with Joaquin recording everything in meeting minutes.

For more detailed ideas, we utilized a whiteboard to easily communicate ideas and make changes to see the impact they had on the overall design (/03 Artifacts/Meeting Artifacts/Diverging Solutions/Full_Value_Proposition.jpg).

For team decisions, we initially opted for a democratic process to make decisions faster. (ex. when we chose to pursue 'improving detection' or 'improving prevention' (01 Meeting Agenda and Minutes/DD1 Or Phase 1/Jan 31. 2023)). Between phase 1 and 2, we conducted a team process review in order to analyze our previous work and create strategies for phase 2: 03 Artifacts/Meeting Artifacts/Team Process Review - Feb 28.docx.

We faced several unexpected challenges as a team over the course of DD2. Two team members got sick which impacted their ability to contribute. This tested our teamwork, as we fell behind schedule and had to come up with a plan to catch up. Luckily, we were mostly working on our CAD design at this point, so the sick team members could still complete some tasks. Another team member was unable to come to campus the week of March 27th, which also impacted progress on the project. They pivoted to coding our motors to continue contributing.

More prototyping meetings were held after reading week. Planning occurred informally on our discord server which led to a few miscommunications that could have potentially been avoided. One portion of the VTS needed to be reprinted and a discussion on Discord occurred verifying this, but the teammate responsible for submitting print orders missed this. This led to a delay that could have been avoided if a meeting was held with all teammates present.

Overall, we feel that we've worked well together as a team this semester. By becoming friends, working together became a more enjoyable experience and positively impacted the quality of our project. This facilitated an environment where team members were comfortable asking each other for help when struggling, which helped resolve roadblocks quickly.

Section 2.4 Timeline

The main cause for the noticeable difference between our proposed timeline and the actual timeline was due to the CAD models taking longer than expected. Creating the models was more challenging than anticipated as none of us had significant prior experience. So having all team members work on the CAD model would not speed up the process. Contrary to the original plan, the team was separated into two groups, one responsible for the 3D models and the other responsible for the microcontroller, working in parallel throughout the prototyping stage. This is why the CAD models were created and printed over a longer span of time than planned while work on the code and the circuit started over two weeks in advance of the planned date.

Wk	Planned	What Occurred
7	Develop an electromagnet for lifting the beakers.	We built a small electromagnet using the wiring from our prototyping kit, a nail from MyFab and a AA battery from Joaquin's mouse. It was very weak and could only lift a small nut. We decided to meet with our E & M prof to discuss this. (01 Meeting Agenda and Minutes/DD2 or Phase 2/Feb. 28 2023).
8	Prototype VTS and RTS. Laser cut/3D print parts and test them.	State Diagram designed (03 Artifacts/Prototyping Artifacts/Software Components/state_diagram_1.0.png)
		We met with Professor Stickel to discuss the electromagnet. He gave us resources to calculate the strength of an electromagnet. We found that an electromagnet would be too weak for our purposes (03 Artifacts/Prototyping Artifacts/Planning and CAD/Electromagnet/ESC204_Electromagnet).
		This week we created a task list for all the components that needed to be modeled in CAD (01 Meeting Agenda and Minutes/DD2 or Phase 2/Mar. 10 2023). The geneva mechanism was 3D printed from a stl file found online.[10]
9	Prototype a basket to hold the microscope slides.	Pseudocode created (03 Artifacts/Prototyping Artifacts/Software Components/eugene_pseudo_code.png)
		First revision of code created and tested. State functions were functional. (03 Artifacts/Prototyping Artifacts/Software Components/EJ Praxis Code 1.2.py)
		We continued CAD work. (01 Meeting Agenda and Minutes/DD2 or Phase 2/Mar. 14 2023) The box was designed for 5mm thick plywood, but MyFab only supplies 3mm thick plywood. We had to reCAD the box to account for this, so we cut two 3mm sheets of plywood to create a box with 6mm thick walls (01 Meeting Agenda and Minutes/DD2 or Phase 2/Mar. 17 2023).
10	Assemble subsystems into final prototype. Debug software.	Assembled a circuit which connected the Raspberry Pi to one stepper motor.
		Produced the first successful revision of the code in which both the state functions and the motor functions were implemented. (03 Artifacts/Prototyping Artifacts/Testing/Mechatronic Tests/code_state_testing_ITWORKS.mp4)
		The first box was assembled, and the RTS system was assembled and tested by rotating the gears by hand (01 Meeting Agenda and Minutes/DD2 or Phase 2/Mar. 21 2023).
11	Verify the prototype, developing proxy tests related to our requirements model and stakeholders.	Modified the circuit to accommodate the simultaneous use of two stepper motors for both RTS and VTS. A strange phenomenon occurred when the code was tested: the motors only moved when a hand was placed near the circuit.
		We assembled the new box, glued it together, and attached VTS and RTS components. The geneva mechanism was discarded after testing the precision of the stepper motors.
12	The final week is reserved for sorting out integration problems and writing our second Design Dossier.	The issue regarding the circuit responding only to the presence of a hand was resolved. The majority of DD2 was completed this week. We recorded a video meeting and worked on prox tests for our prototype.

Section 3. Annotated List of Supporting Artifacts

Section 3.1. Folder system:

/Team 0106B

-> /00 General Resources
-> /01 Meeting Agenda and Minutes
-> /02 Research
-> /03 Artifacts

Section 3.2. General Resources:

Praxis III assignments:

Path: /Team 0106B/00 General Resources

The project handouts and opportunity statements are here for easy reference on the specific concepts, requirements, and constraints in the project assignment. The third document is the Opportunity Statement, which was important to have on hand during preliminary work. Throughout the design process, we constantly referred to these documents to answer questions we had about the assignment and as a guide throughout our process. They also helped inform the different components of the design dossier, such as our meeting minutes, artifacts, and how we organized our work.

Team Charter:

- ➔ Team Charter - Revised

Path: /Team 0106B/00 General Resources

This document is our Team Charter, which we developed during Studio 1A to guide our future group work and design efforts. It includes our team's basic information, goals, expectations, communication and interaction protocols, as well as our strategies. This document played a key role in keeping us aligned with our overall strategy and prevented prolonged disagreements over major decisions, thanks to our clear interaction protocol. Additionally, it outlines our personal goals for this course, which helps us determine the direction of our design process and ensure that we achieve these goals.

Schedule, Team Responsibilities, and Budget:

- ➔ Schedule_Responsilbiity_Budget

Path: /Team 0106B/00 General Resources

This document contains three things. Our overall groups schedule and deadlines, our individual responsibility, and the budget of our project. These documents help us keep track of all our project tasks and responsibilities as our time becomes more demanding throughout the term. It also helps keep us all accountable since everyone can see what we have or have not done yet.

Meeting Minutes:

Path: /Team 0106B/01 Meeting Agenda and Minutes

These documents are the notes and minutes taken during and after our team meetings. These documents were very important to remember our thoughts and ideas from meeting to meeting. When we were writing ideas on whiteboards, minutes were still being taken so we had the information written down twice. A lot of our re-summarizations of divergence and convergence were derived from the meeting minutes as they were the main source of recorded information. These minutes also contain the advice that TAs gave us throughout the design process.

For better organization, the artifacts are split between Phase 1 and Phase 2, in the two folders: /DD1 Or Phase 1 and /DD2 Or Phase 2. This allows us to easily look at more recent conversations for Phase 2 but also helps anyone else who wishes to specifically look at our Phase 2 work.

Section 3.3. Phase 1 Resources:

RDT Research:

- ➔ Joaquin Research Weekend 21-22

Path: /Team 0106B/02 Research

The document contains notes on Rapid Diagnostic Tests (RDTs) used to detect infectious diseases. It discusses the need for a machine that can quickly read RDTs and the process of preparing and analyzing a sample. The document also touches on the disposal of RDTs and the key components of an RDT, including the buffer, lysing chemical, and specific antibodies used in the test. This information was used to check the feasibility of different pathways we could go through for this challenge (02/Meeting Agenda and Minutes/Jan 23. 2023). In the end we chose to focus on Microscopy instead of RDTs.

Microscopy Tools Research:

- ➔ Microscope, hematology analyzer, chemistry analyzer, urinalysis machine, Glucometer

Path: /Team 0106B/02 Research

The document provides information on various medical laboratory equipment including a microscope, hematology analyzer, urinalysis machine, and glucometer. The document summarizes the different components of these machines and how they are used to analyze and test for Malaria. Due to the complexity of these machines, we decided to focus on the logistics of the slides, rather than improving any of the specific mechanisms of these testing machines.

RDT Finance Research:

- ➔ RDT Market Research

Path: /Team 0106B/02 Research

The document discusses the market for rapid diagnostic tests (RDTs) for malaria, which has four sources of medicine: public sector (e.g. WHO), private sector (for-profit, less expensive), proprietary and patent medicine (unlicensed, sold in convenience stores), and drug hawkers (illegal and fraudulent). The document notes that the issue of unlicensed and illegal medicines is a serious problem, but it is not something that can be solved within the scope of this project. As such we did not move in this direction when considering our value proposition.

Value Proposition Discussions:

Path: /Team 0106B/03 Artifacts/Meeting Artifacts/Value Proposition Discussions

These photos were taken during the Feb. 7 meeting (01/Meeting Agenda and Minutes/Feb. 7 2023). They specifically show our work in developing a context scope, approach scope and value proposition. This all came together to become our Requirements model. These artifacts highlight our approach to this challenge and our thinking processes.

Diverging Solutions:

Path: /Team 0106B/03 Artifacts/Meeting Artifacts/ Diverging Solutions

These photos represent the different solutions we considered for this project. These happened during many different meetings as we sometimes came up with ideas on the spot. The two inventory check images were from when we needed to check what materials MyFab had and whether a whole idea was feasible based on the materials constraint. The Malaria Preventative Designs image is from when we were considering solutions that prevented Malaria.

Detailed Design:

Path: /Team 0106B/03 Artifacts/Meeting Artifacts/Detailed Design

These photos are the more specific design considerations of our automated robotic arm design. These different images show the different components of our design, from the deep fryer-like baskets to the specific motions we need the robotic arm to do. A lot of these images are high-level and haven't fully considered the different materials we have available. These more specific testing, prototyping, and material consideration will happen post reading week. These photos were taken during the latter meetings of this phase.

Teamwork:

Path: /Team 0106B/03 Artifacts/Meeting Artifacts/Teamwork

These images show our team bonding activities. We had three major activities throughout this phase, a Google Ghost game, eating together, and an Among Us game. These activities helped bring us closer together and get to know each other on a personal level. They also gave us fun relief from a mostly work-filled project. Learning more about each other facilitates better teamwork, and a deeper understanding of each team members' strengths and weaknesses. In the hit game Among Us, 'crewmates' work together to complete a series of tasks to keep their spaceship running, much like how each team members' individual tasks keeps a project afloat. One player plays as the 'impostor', whose goal is to sabotage the crewmates. Playing this game together revealed how well each team member works in stressful conditions.

Studio:
Path: /Team 0106B/03 Artifacts

These photos and videos were taken throughout the labs we worked on during practical sessions. The purpose of the labs was to allow us to develop a basic set of technical skills from scratch, as they will be useful in the assembly of our high-fidelity prototype. The photos and videos showcase our progress in developing these skills and in our ability to apply them for other uses.

Annotated Bibliography:
Path: /Team 0106B/02 Research/Annotated Bibliography.docx

This document contains an annotated list of some of the sources we used for research throughout our design process thus far. While not formally written out, other sources we used followed the same CRAAP test structure to ensure the credibility of the information we gathered.

Section 3.4. Phase 2 Resources:

Team Process Review:
Path: /Team 0106B/03 Artifacts/Meeting Artifacts/Team Process Review - Feb 28.docx

This team process review was conducted on February 28th to review our previous work during Phase 1 and how we individually contributed to Design Dossier 1. From the feedback and notes in this process, we created strategies and considerations for the next phase of our project. This helped us to remain an efficient team throughout the rest of the project.

Prototyping Artifacts:
Path: /Team 0106B/03 Artifacts/Prototyping Artifacts

The Prototyping Artifacts folder is divided into subfolders that separate several processes. The Electronic Components folder contains our final circuit, and photos of the motors installed on the prototype.

Pre-Manufacturing and CAD:
Path: /Team 0106B/03 Artifacts/Prototyping Artifacts/Planning and CAD

The planning folder consists of all our plans for the prototype before we started manufacturing and assembling components. These include whiteboard sketches with measurements, CAD drawings of the components, and our discussions about using an Electromagnet. Also in this folder is a collection of timelapses of the different CAD files.

Prototype Creation:
Path: /Team 0106B/03 Artifacts/Prototyping Artifacts/Manufacturing and Construction

The creation folder contains all our artifacts about manufacturing the different components and constructing the prototype together. This folder consists of many photos and videos while we built and assembled the prototype. Most of these photos and videos were taken in MyFab as we worked in that space for most of the construction process.

Prototype Electronics:

Path: /Team 0106B/03 Artifacts/Prototyping Artifacts/Electronic Components

This folder consists of artifacts relating to the electronic components which were designed and tested separately from the rest of the prototype initially. This folder deals a lot about the two stepper motors we used in the prototype, as well as the breadboard circuit we used to control them.

Prototype Code:

Path: /Team 0106B/03 Artifacts/Prototyping Artifacts/Software Components

This folder consists of the tools we used to code the prototype code, and the actual code in its different iterations. These code files were sent back and forth between Eugene and Joaquin as they worked on the software of the prototype.

Testing Physical Prototype:

Path: /Team 0106B/03 Artifacts/Prototyping Artifacts/Testing

The Testing folder consists of every video we have about the testing features of the prototype. This is split up between General Tests, which refer to more human tests surrounding the prototype, Mechanical Tests, which are tests about the mechanical components of the prototype such as the VTS and RTS, and finally Mechatronic Tests, which is a combination of the electrical components and how those electronics integrate with the mechanical prototypes. This last folder contains the final tests of the Mechatronic prototype, which show that the final prototype works as intended and meets our requirements.

Section 4. Works Cited

[1] Praxis III Staff, “Making Health Services Accessible.” University of Toronto, Toronto.

[2] N. Adebowale-Tambe, “Malaria contributes to reduced economic growth in Nigeria, other African countries – WHO,” *Premium Times - Nigeria leading newspaper for News, investigations*. [Online]. Available: https://www.premiumtimesng.com/news/top-news/457401-malaria-contributes-to-reduced-economic-growth-in-nigeria-other-african-countries-who.html?tztc=1. [Accessed: 19-Feb-2023].

[3] “CDC - Malaria - Diagnostic Tools,” *Centers for Disease Control and Prevention*, 12-Jan-2023. [Online]. Available: https://www.cdc.gov/malaria/diagnosis_treatment/diagnostic_tools.html#tabs-1-1. [Accessed: 19-Feb-2023].

[4] H. M. Edwards, R. Sarwar, P. Mahmud, S. Emmanuel, K. Maxwell, and J. K. Tibenderana, “The private sector market for Malaria Rapid Diagnostic Tests in Nigeria: Results of the 2018 market survey - malaria journal,” *BioMed Central*, 16-Jun-2022. [Online]. Available: https://malariajournal.biomedcentral.com/articles/10.1186/s12936-022-04209-3. [Accessed: 19-Feb-2023].

[5]“Giemsa staining of malaria blood films,” *World Health Organization*. [Online]. Available: https://www.who.int/publications/i/item/HTM-GMP-MM-SOP-07a. [Accessed: 19-Feb-2023].

[6]U. I. Omale, O. U. Oka, I. M. Okeke, B. N. Azuogu, C. Alo, U. C. Madubueze, I. I. Eze, K. C. Okeke, R. Utulu, U. E. Akpan, C. V. Iloke, A. O. Nnubia, D. O. Ibemesi, C. R. Nnabu, and O. C. Anene, “Demand for malaria rapid diagnostic test, health care-seeking behaviour, and drug use among rural community members with fever or malaria-like illness in Ebonyi State, Nigeria: A cross-sectional household survey,” *BMC Health Services Research*, vol. 21, no. 1, 2021.

[7]*Malaria Microscopy - A Step by Step Guide*. YouTube, 2015. https://www.youtube.com/watch?v=vo-JmxTEtk4

[8] T. Mutabazi, E. Arinaitwe, A. Ndyabakira, E. Sendaula, A. Kakeeto, P. Okimat, P. Orishaba, S. P. Katongole, A. Mpimbaza, P. Byakika-Kibwika, C. Karamagi, J. N. Kalyango, M. R. Kamya, G. Dorsey, and J. I. Nankabirwa, “Assessment of the accuracy of malaria microscopy in private health facilities in Entebbe Municipality, Uganda: A cross-sectional study,” *Malaria Journal*, vol. 20, no. 1, 2021.

[9] “Global Variables are Evil,” *University of San Francisco, College of Arts and Science*. https://www.cs.usfca.edu/~wolber/courses/110/lectures/globals.htm

[10] Geneva Mechanism. https://cults3d.com/en/3d-model/gadget/geneva-mechanism

[11] “Average Medical Laboratory Technician salary in Nigeria,” PayScale, Mar-2023. [Online]. Available: https://www.payscale.com/research/NG/Job=Medical_Laboratory_Technician/Salary.