Supporting Information – **3D Printed Laboratory Accessories as a Conduit for a Multidisciplinary Undergraduate Research Experience**

3D Printing: Selection of Printer and Filament

The 3D printing lab at ECU Joyner Library currently has three different 3D printer options, each with its own printing capabilities: a Lulzbot TAZ 5, an Ultimaker 3, and a Fusion3 F400-S. The Lulzbot printer is best utilized for medium to large but rather simplistic designs and an ideal choice for the beginning 3D modeler. This Ultimaker printer is used for more complex parts requiring a stronger level of detail for completion. This printer also has the unique capability of providing water (H_2O) soluble supports for delicate or rather intricate parts of a design. The Fusion 3 printer is mainly used for more highly skilled and detailed 3D models as it can more easily form complex parts, small or large, with a high level of accuracy.[26]

In addition to choosing between different 3D printers, users must also select the most appropriate filament material for constructing their printing projects. In the ECU printing lab, there are currently seven filament options: Polylactic Acid (PLA), Polyethylene coTrimethylene Terephthalate (PETT), Acrylonitrile Butadiene Styrene (ABS), Nylon, Acrylonitrile Styrene Acrylate (ASA), Polyethylene Terephthalate Glycol (PETG), and Thermoplastic Polyurethane (TPU).[27] The characteristics and applications of each material are outlined in Table 1 below. For the projects printed in this study, polylactic acid (PLA) filament was an economical choice that also provided sufficient strength and solvent tolerance.

Table 1. Types, Characteristics, and Uses of Filaments Offered by the ECU 3D Printing Laboratory.[27]

Filament Type	*Characteristics*	*Applications*
PLA	Cheap, Detail, Precision, Surface Quality	Visual Imaging, Prototyping, Modeling, Low-Wear Projects, Containers
PETT	Strength, Impact Resistance, FDA Approval, Transparence	Artistic Prints, Bracelets, Light-Pipes, Vases
ABS	Impact Resistance, Durability, Large Model Capability, Heat Tolerance	Protective Casing, High-Wear Projects, Tool Handles, Functional Parts
Nylon	Strength, Durability, Flexibility, Chemical Resistance	Tools, Functional Models, Mechanical Parts, Structural Parts, Dynamic Loads
ASA	Chemical Resistance, Weather Resistance, Thermal Stability, Impact Resistance, Rigidity	Outdoor Builds, Functional Prototyping, Automotive Parts, Electronic Housing
PETG	High Strength, Impact Resistance, Sterilizable	Bracelets, Mechanical Parts, Functional Parts, Protective Casings
TPU	Flexibility, Impact Resistance, Durability, Chemical Resistance	Toys, Seals, Stress Relief Objects, Plugs

Project Reflection – ________

Prior to the creation of this project I had been exposed to a variety of team/group-based work through the Engineering curriculum at East Carolina University. This came from many sources with some being smaller classroom group projects, and others ranging to rather intense and rigorous long-term projects such as that of my Engineering Capstone Final Project that encompassed my entire senior year of undergraduate education. Because of this, team science and project-based learning were not exactly new concepts to me when deciding to take on this specific project.

However, while the engineering curriculum prepared me for this learning aspect. Inter-disciplinary team-based learning, i.e. chemistry and engineering students working collaboratively, was something that was rather new to me. Working on a team, wherein the individual team members bring different backgrounds, ideas, and knowledge to the table provides all within the team the ability to work collectively toward a goal that alone may not be possible. Working within a team such as this is also beneficial when any problems/issues arise.

Because 3D printing was, in the earlier project stages, a novel concept to the team members there was some uncertainty involved in how to approach certain designs. It is this aspect of the project that proved to be the main source of difficulty. Precision is of the utmost importance when 3D modeling/printing. This is especially true when the accessory will be subjected to substantial force, such as the centrifugal force experienced by the adapter (**Figure 2**). However, as problems arose throughout the project they were just as easily extinguished through research and iterative trials. As the 3D printing online community is full of open source design downloads/descriptions/instructions, the troubleshooting aspect of this project was quite simple. Outside of exploring the online resources as part of my individual learning when working on this project team, much of my personal learning came from practice. SOLIDWORKS is known for its user-friendly layout and display, however, without considerable exposure to the language, functions, and minor details of the modeling software one would surely experience an array of issues.

Through my own independent learning, as well as through collaboration within the project team, I have learned many new skills, as well as improved on others. Primarily I have improved my ability to efficiently and accurately create 3D designs. In the early stages of the project this process may have taken days or even weeks to produce a functional and precise design, however in the later stages the same design would have only taken hours or even less time. Secondly, my ability to identify problem areas within the lab where a 3D printed solution could be beneficial, has improved. It is often hard to "see" how a 3D printed design would work, or even what it would look like, within a laboratory setting. Often times, especially when 3D printing is a new concept to an individual, it can be hard to visualize and conceive how a 3D printed design could enhance a process or series of processes. With exposure to the design process as well as an understanding of the various processes that occur in a chemistry laboratory this skill has been extremely enhanced through working within this team for the project's duration. Lastly, my ability to work cooperatively within a project team has surely been improved upon. As mentioned, working within a team/group was nothing new to me when taking on this project.

However, the interdisciplinary aspect that this project-team possessed provided immense value to my abilities to work within a team as well as insight into how individuals with different educational backgrounds can benefit one another when working towards a common goal.

Group Epsilon

November 18, 2020

Hand Crank Centrifuge

Problem Statement:

Through reading the problem description carefully and reaching out to the customer (Dr. Hughes), we were able to come together and create a project statement to help guide our design process.

"Many lab procedures require centrifuging to separate solids from liquids in a solution. Electric centrifuges are typically expensive and have electronic components that are susceptible to break. They also use electricity, which makes them a less green alternative to completely human powered options. They also cannot be used in labs that do not have access to power or have unreliable power. Our objective is to make a centrifuge that is completely powered by human force to solve all of these issues."

Ideation:

We got together to come up with different functions that we could generate alternative options for. We then compiled them into a morphology chart (Figure 1). Using this chart, we were able to generate 3 alternatives for our design based on key design differences that would affect our final design the most.

- Alternative 1 has a design layout where a hand crank centrifuge will be powered by a crank arm. The crank arm will be manually rotated. This design will hold 1.5 -15mL tubes according to the industry standard. The tubes will sit at a 45-degree angle instead of 30 or 60. All tubes will be covered in this design compared to the next two alternatives which covers only a specific number of tubes. Alternative 1 uses special gears to efficiently transfer crank motion to the centrifuge.
- Alternative 2 is a design is powered by a wheel that is manually turned by the user. This design holds 24 tubes of 1.5mL and the tubes will sit at 30-degree angles instead of 45 or 60. Each tube has its own unique cover unlike the other alternatives. This design will use chains to effectively transfer crank motion to the centrifuge.

- Alternative 3 is the most complex of the alternative solutions but it is the most practical. A manual pressure-controlled device allows the user to power the centrifuge will a press of a button. This feature satisfies the requirement of manual operation while also reducing the amount of labor needed for work to be done. This design will hold 8-12 tubes of 1.5mL at a 60-degree angle. The tubes are covered in a diagonal pair which is less practical than both the previous alternatives but still can be considered based on the ease of use.

Figure 1: Morphology Chart

Means Functions	Alternative 1	Alternative 2	Alternative 3
Powered Completely by humans	Crank arm that can be rotated	Wheel that operator can turn	Manual pressure-controlled device
Have room for enough test tubes	Will hold 4 to 6 tubes of 1.5mL (industry standard)	Dr. Hughes recommended 24 tubes of 15mL	Dr. Hughes recommended 8 - 12 tubes of 1.5mL
Make sure that the solids can be separated in the tube	Tubes sitting at a 45° angle (industry standard)	Tubes sitting at 30° angle	Tubes sitting at 60° angle
Tubes need to be covered	Cover the entire tube area	Cover each individual tube	Cover by diagonal pair
Easy to use	Not difficult to operate	Lightweight for portability	Tubes can be easily inserted and removed
Efficiently transfer crank motion to the centrifuge	Use gears to transfer the energy	Use a chain to transfer energy	User directly turns the centrifuge vials
Ease of manufacturing	Doesn't use a lot of material to make	Assembly doesn't have a lot of steps	Doesn't require any difficult to obtain parts
Versatile	Works from tube sizes from 1.5mL-15mL	Can be used for many different chemical solutions	Can be used for many different medical or chemical applications

Feasibility:

In this Feasibility Chart (Figure 2) we looked at all the alternatives for the functions we came up with and decided if they were feasible or not. If an alternative was infeasible, we gave a description of why we felt it was infeasible.

Figure 2: Feasibility Chart

Functions	Alternatives	Feasible (Y/N)	Reason for infeasible	Possible Modification
Powered Completely by humans	Crank arm that can be rotated	Y	N/A	N/A
	Wheel that operator can turn	Y	N/A	N/A
	Manual pressure-controlled device	Y	N/A	N/A
Have room for enough test tubes	24- 1.5mL tubes (industry standard)	N	Beyond the scope of our capabilities	Less tube slots
	Dr. _____ recommended 4-6 15mL tubes	Y	N/A	N/A
	Dr. _____ recommended 8-12 1.5mL tubes	Y	N/A	N/A
Make sure that the solids can be separated in the tube	Tubes sitting at a 45° angle (industry standard)	Y	N/A	N/A
	Tubes sitting at 30° angle	N	Not most efficient for certain lab procedures	None
	Tubes sitting at 60° angle	N	Not most efficient for certain lab procedures	None
Tubes need to be covered	Cover the entire tube area	Y	N/A	N/A
	Cover each individual tube	Y	N/A	N/A
	Cover by diagonal pair	Y	N/A	N/A
Easy to use	Not difficult to operate	Y	N/A	N/A
	Lightweight for portability	Y	N/A	N/A

	Tubes can be easily inserted and removed	Y	N/A	N/A
Efficiently transfer crank motion to the centrifuge	Use gears to transfer the energy	Y	N/A	N/A
	Use a chain to transfer energy	Y	N/A	N/A
	User directly turns the centrifuge vials	Y	N/A	N/A
Ease of manufacturing	Doesn't use a lot of material to make	Y	N/A	N/A
	Assembly doesn't have a lot of steps	Y	N/A	N/A
	Doesn't require any difficult to obtain parts	Y	N/A	N/A
Versatile	Works from tube sizes from 1.5mL-15mL	Y	N/A	N/A
	Can be used for many different chemical solutions	Y	N/A	N/A
	Can be used for many different medical or chemical applications	Y	N/A	N/A

Decision Matrix:

As a group after finishing the feasibility chart (Figure 3), we listed the most important constraints to see how our design alternatives compare to each other. Based off the nature of the project and the email response from our email to Dr. Hughes, team Epsilon came up with a weight system that ranked the importance of each constraint as we saw fit. For example, we weighed cost less than limiting wobble of centrifuge since the design will be compromised if it does not limit the wobble of the centrifuge whereas cost is important, but not as important as something that can make or break our final design. Based on this chart, we decided to do a hand crank centrifuge with all of the features mentioned in Figure 2 that were feasible.

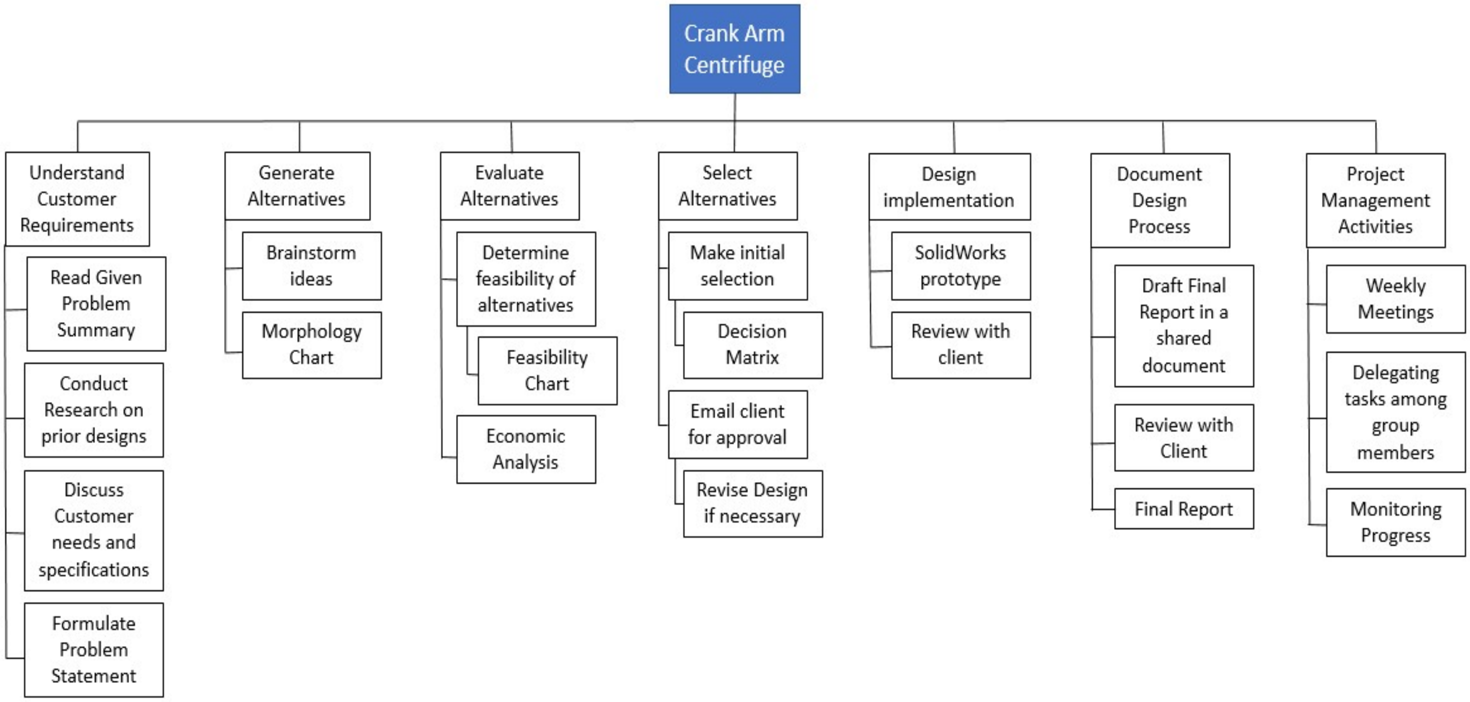
Figure 3: Decision Matrix

Attribute/ Constraint	Weighted Factor	Alternative 1	Alternative 2	Alternative 3
Brief Description		Crank Arm that powers the device	Operator Wheel that powers device	Manual Pressure-Controlled Device
Limits wobble of centrifuge	20%	5 **1**	6 **1.2**	7 **1.4**
Easy and comfortable to use	15%	6 **0.9**	8 **1.2**	9 **1.35**
Can be easily conceptualized and implemented	40%	8 **3.2**	5 **2**	4 **1.6**
Cost	10%	7 **.7**	6 **.6**	3 **.3**
Ease of Manufacturing	15%	8 **1.2**	7 **1.05**	5 **0.75**
Total Scores	100%	**7**	**6.05**	**5.4**

WBS Chart:

This Chart (Figure 4) helped us structure our project on every needs or things that needed to get done. Scheduling chart that includes the critical path for the construction/manufacture of the prototype of your laboratory accessories.

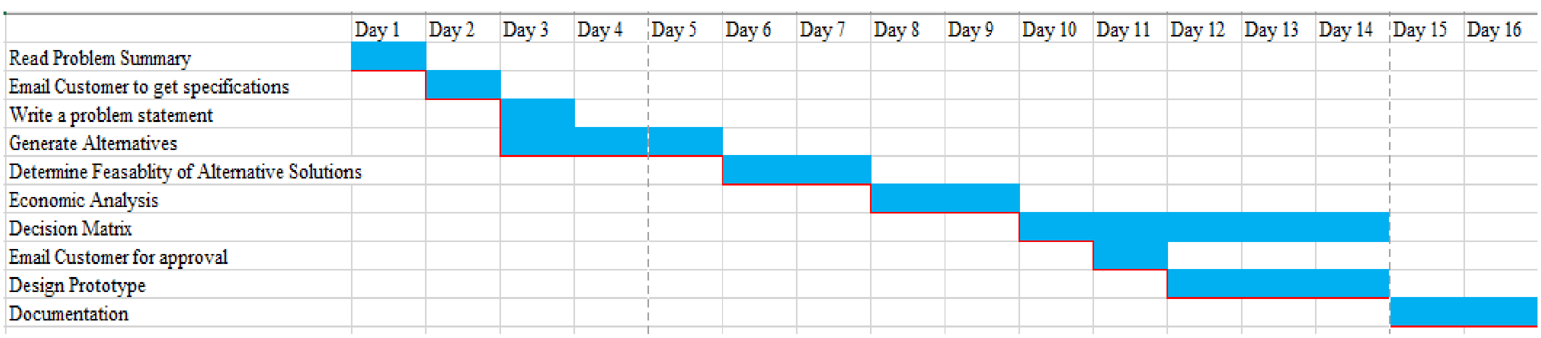
Figure 4: WBS Chart



Gantt Chart:

This chart schedules our time on how much time we spent going through each step of the project. The Gantt Chart (Figure 5) is special because it allows us to establish a critical path. This also help us find the quickest method to complete our project.

Figure 5: Gantt Chart



Economic Analysis Information:

To do the economic analysis we modeled a first rendition of the product in SolidWorks. We then used that design to make a bill of materials shown below. We calculated the price for each component of the unit, and then calculated the total cost for that unit which came out to be $3065.50. Then, we estimated the time to print each object and researched the average salary of a person who oversees 3d printing of objects and calculated the price of that person's salary. We multiplied the time it would take to make the object by the hourly wage of the worker. We did this because 3d printing requires someone to oversee the print to ensure the quality of the print. After this, we researched the cost to rent a 3d printer and factored that into the cost of the object cost. In total, one object ended up costing a total of $3457.54. We factored the cost of a screwdriver into the cost of 100 items, because 1 should be able to last all 100 products, and a screwdriver is the only tool that should be needed to assemble this object. The total manufacturing cost of 100 products is roughly $345,754.97. This does not consider facility costs and their associated sub costs such as facility cleaning, electricity, etc.

This design saves the owner money over time thanks to its easy maintenance and repair. While other centrifuges are difficult to repair, this model will allow the owner to easily switch out broken parts due to a simplified structure and the ability to print replacement parts. Over the course of use, this product will continue to provide a reliable alternative to powered centrifuges. Since most of the cost is from the main body of the centrifuge, the price could be reduced by utilizing a different production method and material. Those changes would cut down on the initial price.

Table 1: Bill of Materials

Part/Material	Quantity	Price per unit	Time to print object (hours)
Gear Main	1	$9	.15
Gear primary	1	$10.50	.15
Crank arm	1	$96	.5
Top Dome	1	$371	1.2
Body Case	1	$2483	8
Hinge	1	$2	.05
Screws	20	$0.30	Not printed
Center shaft	1	$77	.35
Shaft	1	$10	.15
Latch	1	$1	.05

Economic Analysis:

Total cost for 1 unit: 3,065.50

Time to print 1 object: 10.6 hours

Time to assemble 1 object: .75 hours

Time of 1 object total: 10.6 + .75 = 11.35

Labor cost per hour: $34.24 /hr.

Rent a 3d printer: $50/wk. so $0.30/hr.

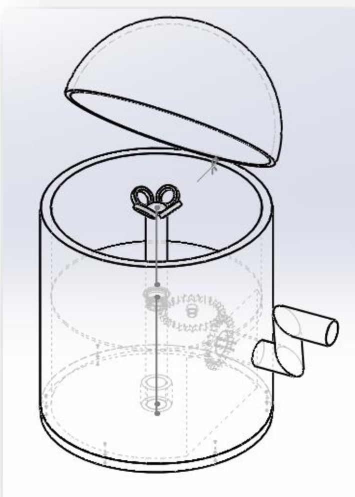
Price to 3d print object on printer: 11.35 * $0.30 = $3.41

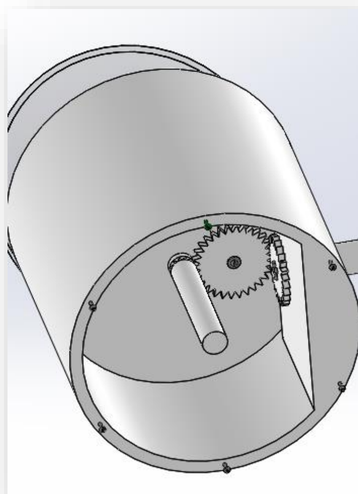
Price of screwdriver: $0.97

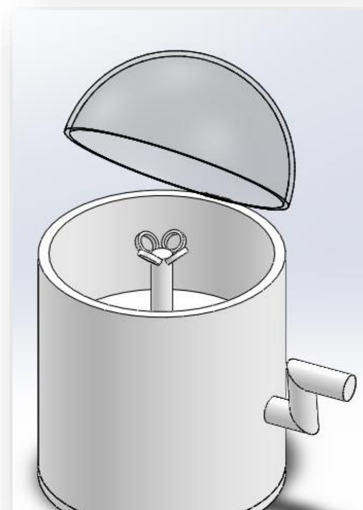
Price of 1 object total: 3,065.50 + (11.35 * 34.24) + 3.41 = $3457.54

Price of 100 objects: = $345,754.97

Our Final Product Design:







Conclusion:

Our objective was to create a centrifuge that is completely powered by human force. Through several methods of project management, we were able to come up with a design that solves the problem of needing a centrifuge that is not powered by electricity. This design is economical, environmentally friendly, and easy to manufacture while also satisfying all of the specifications that the customer gave us.

Student Survey for ABET Outcomes for ENGR 2000

Outcome 2: apply engineering design to produce solutions that meet specified needs.

1. I can successfully complete an engineering design that includes realistic constraints.

   1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

2. I can develop a well-defined problem statement with constraints from an ill-defined problem.

   1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

3. I can develop multiple solution alternatives to an engineering design problem.

   1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

4. I can select and justify the best solution from a list of solution alternatives.

   1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

Outcome 4: understand the impact of engineering solutions.

5. I understand multiple ways that the practice of engineering can impact others.

   1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

Outcome 5: function effectively on a team.

6. I can effectively function on a multi-disciplinary teams.

   1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

Outcome 7: ability to engage in life-long learning.

7. I can independently obtain information I need to complete engineering designs.

   1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

Other

8. I feel that the prerequisite for this course (ENGR 1016) is adequate.

   1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

9. I feel that a textbook should be required for this course.

   1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

10. About how many hours per week on average did you spend outside of class working on this class?