Recycling for 3D Printing at the University of Namibia

An Interactive Qualifying Project Proposal
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Report Submitted to:
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Table of Acronyms

Acronym	**Term**
UNAM	University of Namibia
CAD	Computer Aided Design
AM	Additive Manufacturing
RepRap Movement	Replicating Rapid-prototype Movement
FDM	Fused-Deposition Modeling
SLA	Stereolithography
PET	Polyethylene Terephthalate
PETG	Polyethylene Terephthalate Glycol
CT	Computer Tomography
CAT	Computerized Axial Tomography
MRI	Magnetic Resonance Imaging
STL	Stereolithography
COTS	Commercial-Off-the-Shelf
PID	Proportional, Integral, Derivative
BOM	Bill of Materials
RFID	Radio Frequency Identification

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Abstract

In addition to written materials and diagrams, three-dimensional models are essential to medical education pedagogy. However, many of the materials and models used, such as detailed anatomical models and cadaverous dissections, are typically exorbitantly expensive or ethically contentious. The University of Namibia School of Medicine (UNAM) struggled with acquiring enough teaching materials for students due to supply limitations and funding constraints. One of UNAM's facilities, the Forge3D Lab, attempts to circumvent some of these limitations by 3D printing models and teaching materials. The team interviewed faculty and students at UNAM about medical education and medical ethics and their intersection with 3D printing and technology. The team's findings showed that there are numerous applications for 3D printing within the anatomy, dentistry, and occupational therapy departments at UNAM. Furthermore, the team provided several recommendations about where to direct the Forge3D Lab's resources within UNAM.

In addition to qualitative interviews, the team sourced and manufactured a filament production machine capable of converting waste plastic bottles into usable 3D printer filament. In all, the team completed the bulk of the mechanical assembly of this machine, with about 80% of the machine working. Programming and electrical engineering work will happen after the project's completion, as it can be done remotely. In all, the interviews informed the use cases of the reusable filament that the team hoped to produce, revealing ethical, logistical and resources limitations that go into creating educational tools for medical education.

Executive Summary

Purpose

UNAM's 3D printing facility, the Forge 3D Lab, aimed to create teaching materials by 3D printing models and other materials. However, due to funding constraints, the lab lacks the budget to purchase the filament required to print these materials. The goal of this IQP was therefore to create a device that converts easily available, disposable plastic bottles, made from PET, into a cheap, sustainable source of filament for the Forge3D to use. The team also sought to identify cases within UNAM's anatomy, dentistry, and occupational therapy departments where applying 3D printing techniques could improve the quality of medical education and clinical practice.

Methodology

The team adopted a mixed-methods approach to accomplish both the project's technical and social objectives. For the social component, the team gathered qualitative data through one-on-one interviews with six UNAM professors and technicians. The team also conducted a focus group with occupational therapy students to better understand the perspectives and potential applications of 3D printing within medical education at UNAM. Impromptu, unstructured conversations with students at UNAM helped further understand the viewpoint of UNAM students. Participant observations through informal tours of UNAM departments helped contextualize the possible use cases of 3D printing across the university

For the technical component, the student team developed a Computer Aided Design (CAD) model of a filament extruder and pelletizer which was then constructed from both 3D printed parts and commercial parts. This device, intended for use within the Forge D lab, enables recycling plastic bottles into affordable and functional 3D printer filament.

Deliverables

The team then explored the intersection between the social component and the technical component of the project. The synthesis helped identify some of the needs for specific educational models at UNAM's medical school. Thus, with a source of filament available to the lab, the team then offered realistic recommendations for how capabilities of the Forge 3D Lab could best be used within various departments while avoiding ethical grey areas.

Results

The team's study yielded insights into the complex intersection of technology, medicine, and ethics within UNAM and the greater context of Southern Africa. Interviews with professors at UNAM helped identify many applications of 3D printing in the curricula at UNAM, especially within the anatomy and occupational therapy departments. 3D printing most benefits the anatomy department since it greatly increases the availability of educational materials that are otherwise prohibitively expensive. In occupational therapy, 3D printing has the potential to drastically decrease the time required to personalize assistive devices; it also significantly decreases the cost of these devices, increasing their accessibility in Namibian healthcare. Dentistry benefits the least from the Forge3D Lab's resources, but there are still some areas where 3D printing could help reduce the cost of acquiring essential educational materials.

The ethics within medical education significantly complicates the use of cadaverous materials. Many factors such as availability and cultural norms limit the use of cadavers within medical education. Furthermore, while innovations in technology may help circumvent these issues, the team discovered that technology has greatly outpaced legal and ethical regulations. This leaves 3D printing and other technologies in an ethical grey area.

Finally, the technical component was approximately 80% completed by the end of the project. The mechanical portion of the device was completed, with the remaining work being the electrical and programming portions. However, these components may be completed remotely, so the team kept in contact with the sponsor to finish the device from Worcester.

Recommendations

The team provided a few recommendations to UNAM to improve the medical schools' educational resources using the Forge3D Lab as well as several avenues for future research:Current Recommendations

- 3D print molds of bones and other anatomical parts to allow mass producing cast models rather than printing each piece individually.
- Introduce a course on 3D design and 3D printing within the medical school so that students can learn how these tools may fit into their workflow.

Future Research

- Look into using industrial casting epoxies and resins to find one that behaves similarly to the plastic used to make artificial human teeth.
- Use the Forge3D Lab as a printing service by setting up a portal for UNAM students to pay a small fee to have their models printed.

Report Roadmap

This report comprises six core sections: the introduction, background and context, methodology, results, discussion, and conclusion. The introduction briefly covers the history of UNAM and its Forge3D Lab and some information about the sponsor. The background section provides an overview of 3D printing, 3D printer filament production and recycling, and applications of 3D printing in medicine. The methodology explains population sampling and recruitment, data collection techniques, and measures assessed. The results section summarizes the team's findings, and then the discussion analyzes the team's results and compares the results to existing literature. The discussion also provides outlines suggestions for future works. Finally, the conclusion recapitulates key elements of the paper and explains areas of future study.

1. Introduction

The University of Namibia (UNAM) was established through the University of Namibia Act on August 31st, 1992, shortly after Namibia achieved its independence in 1990 (UNAM History, 2021). Namibia's colonial past under both Germany and South Africa historically prevented local Namibians from accessing higher education; as a result, the newly independent government prioritized education, linking social justice and democratic ideals directly with educational development (Reshad, 2021). With strong government ties, the first chancellor of UNAM was Sam Nujoma, the first president of Namibia. This trend of high-ranking government officials overseeing the institution persists today with the current chancellor at time of writing, Nangolo Mbumba, also acting as the fourth president of Namibia.

Today, UNAM boasts twelve campuses across Namibia, offering programs on everything from agriculture and engineering to management and law (UNAM Corporate Video, 2023). In response to the country's shortage of doctors and surgeons, the UNAM School of Medicine was opened in 2010 in Windhoek on the Hage Geingob campus, becoming the first and only medical school in Namibia (Cfeditoren, 2022). The School of Medicine offers a Bachelor of Medicine and a Bachelor of Surgery along with a post-graduate degree in Anesthesiology (Cfeditoren, 2022).

In January of 2022, the UNAM School of Medicine opened its Forge 3D printing lab after receiving a grant from Dirisana+, an EU-based organization that aims to improve health sciences education in Southern Africa. The grant allowed UNAM to purchase two 3D printers, an Ultimaker S3 and a Creality CR5 Pro, as well as a supply of filament. The availability of this technology to faculty and students creates many opportunities to improve education and facilitate research. The lab specifically offers consultation services, and the 3D printers are open to all university students and faculty (Namesho, 2023). In November of 2023, the Dirisana+ grant ended, and the Forge 3D lab quickly ran out of the filament needed to run its 3D printers. The Recycling for 3D Printing project aims to help UNAM create a new supply filament by utilizing waste plastic found on campus. The sponsor of this project and one of the major contributors to the establishment of the Forge 3D lab, Dr. Quenton Wessels, serves as an associate professor and head of the Division of Anatomy at the UNAM School of Medicine. His original concept for the project saw the development of a machine to convert waste plastic into cost-effective filament, enabling the lab to remain operational for both students and faculty.

2. Background

This section presents a brief introduction to fused-deposition modeling (FDM) 3D printing and provides much needed context for any reader unfamiliar with the technology. A further exploration of Namibia's recycling practices sheds light on the availability of plastic waste, crucial for the project's primary objectives. Using this knowledge of plastic waste in Namibia, the team will examine how recycled plastic bottles can serve as a viable material for 3D printer filament.

2.1. Fundamentals of 3D Printing

Traditional manufacturing methods are primarily subtractive: material is removed from a larger piece of stock to create the desired product. By contrast, 3D printing is an additive manufacturing (AM) process where material is added layer by layer to create a finished part from the base upwards (Campell, 2011). Compared to traditional manufacturing methods, 3D printing, and AM allow for more complex objects and geometries to be made both faster and much more easily. Due to the development of AM in the last decade, both the cost of manufacturing and the time it takes to prototype parts have reduced significantly. Thus, for a time, additive manufacturing was referred to as "rapid prototyping" since users could so easily turn their ideas into a reality (Campell, 2011).

The RepRap movement (short for Replicating Rapid-prototype movement) started the trend of hobbyists developing and sharing designs for relatively inexpensive home-made 3D printers (Ehrenberg, 2013). Widely recognized as the movement that popularized consumer level FDM 3D printers, the RepRap movement propagated 3D printing as a hobby and as a viable tool for manufacturing in many industries (Ehrenberg, 2013). Both of UNAM School of Medicine's printers, the Ultimaker S3 and the Creality CR5 Pro, are FDM printers. FDM 3D printers work by heating a strand of plastic, called filament, and extruding it through a nozzle. A computer controls the position of the nozzle, meaning the printer can deposit plastic in any position within its reach to create a full model. Different filaments with different material properties accommodate specific needs. For example, TPU plastic filament creates flexible parts while PLA is known for its rigidity and low cost

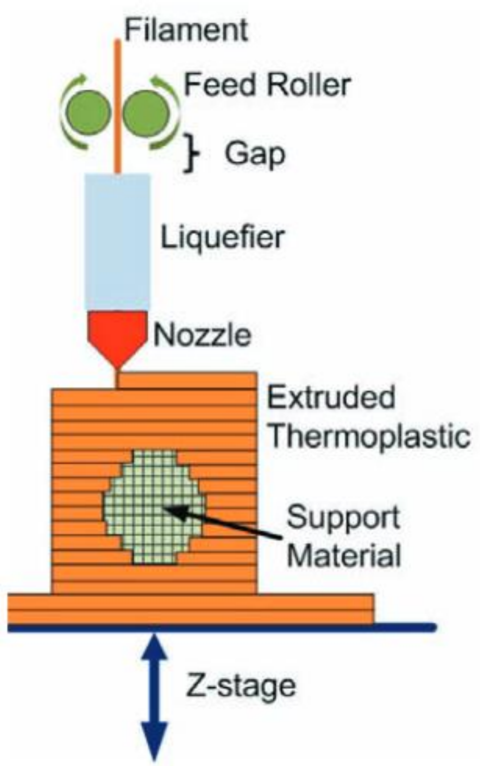

Figure 1: Function of a FDM 3D Printer (Campbel, 2011)

Like all forms of manufacturing, additive manufacturing requires raw materials. In the case of 3D printers, the raw material is filament. While the cost of filament is generally much cheaper than the materials required for subtractive manufacturing (Campell, 2011), the cost is still not negligible (Ultimaker, 2023). According to Ultimaker, the makers of the Ultimaker S3, the cost of a single one-kilogram roll of PLA plastic filament, generally the cheapest filament, costs between $20 and $50 USD. Other, more specialized plastic filaments can cost significantly more: upwards of $60 USD or more per kilogram (Ultimaker, 2023).

Though $20-$50 USD for one-kilogram of filament seems relatively manageable, a simple 3D-printed cast for a forearm uses as much as one hundred grams of raw material (Lin et al., 2015). As a result, printing only ten casts for student research would cost UNAM a minimum of $20 USD in materials. For example, if the university prints only twenty casts per month, it equates to a material cost of $480 USD per year. With most practical 3D prints for medical research or educational tooling requiring between fifty and two hundred grams of filament, if multiple student or faculty projects wish to rapidly prototype, the cost of materials for the Forge 3D lab quickly exceeds the lab's budget.

There have been efforts to create affordable means of recycling failed 3D prints and plastics back into usable filament. The efforts have come from both commercial entities such as Filastruder, Felfil Evo, and 3devo, and the hobbyist community (O'Connell, 2023).

The commercial sector offers professionally designed machines capable of reliably producing filament from scrap plastics. Unfortunately, these machines' primary market of large manufacturing plants makes these devices prohibitively expensive: the Felfil Evo is one of the cheaper options, and their website markets their filament extruder at roughly 800€ (about $850 USD) as of February 2024 (felfil.com/product-category/filament-extruder). Meanwhile, the hobbyist community has developed more cost-effective solutions at the expense of the robustness of a commercial product. Thus, a goal of this project is to find a low-cost solution that is reliable enough to provide a consistent supply of filament for the University of Namibia's School of Medicine.

2.2. Recycling and 3D Printing

The most common types of plastic waste in Namibia are single-use plastic bags and packaging. A case study conducted about waste disposal in Namibia described that "Every solid waste disposal site in Namibia is distinguished by the presence of plastic bags and packaging littered throughout the landscape" (Shakalela, 2023). A significant portion waste in Namibian disposal sites is plastic water bottles, which are made of polyethylene terephthalate (PET), a plastic very chemically similar to polyethylene terephthalate glycol (PETG), a common material for 3D printer filament (Nikam et.al., 2023). PETG is a modified version of PET, with the "G" at the end of the name referring to the added glycol molecule that reduces the material's crystallinity and makes it easier to 3D print compared to normal PET (Nikam et.al., 2023). While PETG is easier to print than PET, PET is still an excellent material for 3D printer filament. Furthermore, precedent exists for converting plastic water bottles into reliable 3D printer filament.

A paper published by Woern et al (2018) describes the process of plastic recycling. The process for recycling plastic into usable filament roughly comprises three main steps: cleaning the plastic waste to remove contaminants, shredding, and grinding the plastic into grains, and then melting and extruding the grains into filament. To create reliable filament, the source of plastic needs to be clean so that the quality of the plastic is not affected. Most plastics, including PET bottles, can be easily cleaned by rinsing them with soap and water. The plastic is then pelletized or shredded into uniform grains; this makes feeding the plastic into the extruder easier. Finally, an extruder, made up of an augur moving through a heated chamber to a nozzle, slowly melts the grains of plastic and extrudes them as a continuous strand of filament.

While commercial filament extruders and hobbyist machines focus on turning virgin plastic pellets into a cheap source of filament, there remains work to be done on the ability of these machines to process the irregular grains and shreds created by plastic shredders and pelletizers (Albi et al., 2014). When grinding plastic bottles into pellets, especially in a noncommercial or hobbyist setting, issues with the flowability of the material are common. Flowability refers to the ability of a material to move through a system, or in this case, the ability of a certain shape and size of plastic pellet to move through an extruder (Edward, 2001). Angle of repose, the angle from the face of a flat surface to the top of a pile of granular solids when piled, is a key factor in determining the flowability of a granulated material (Edward, 2001). Commercially produced plastic pellets and ground bottle flakes have drastically different angles of repose, where the virgin plastic pellets spill over onto a flat surface with ease and the plastic bottle flakes pile up and create a uniform mass. Figure 2 illustrates the difference in flowability between virgin pellets and plastic bottle flakes produced from a homemade grinder (Elekes & Parteli 2021).

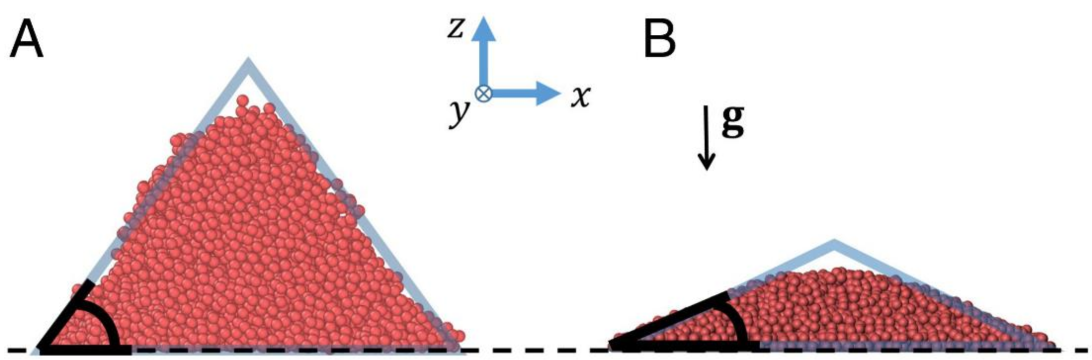

Figure 2: Material with Low Flowability [Left] and High Flowability [Right] (Elekes, 2021).

The two piles shown in the figure result from putting both materials through a funnel onto a flat surface. The commercial material on the right has a very high flowability, causing it to easily flow into a flat pile on the table without external help. On the other hand, the pile on the left stays in one large clump with a much higher angle of repose. Differences in flowability can dramatically change the design of an extrusion system, as certain pellet and grain geometries may require different mechanisms to ensure the proper plastic melting and flow (Elekes, 2021). In industrial settings, shredded plastic water bottles are fed into extruder screws with the use of crammers, agitators, or even two separate feeding screws (Elekes & Parteli, 2021). Without these amenities, the extruder requires an operator present to continuously jostle the shredded plastic into the extruder screw (Elekes & Parteli, 2021).

An alternative process of turning plastic bottles into 3D printer filaments is plastic "pultrusion." Joshi (2012) explains that the typical "pultrusion" process starts by heating a plastic bottle to smooth out all inconsistencies, creating a uniform cylinder from which plastic can be sourced. The plastic bottle would be spiralized into a long thin ribbon of plastic before being pulled through a small, heated nozzle that curls the ribbon into a hollow tube of filament. The filament can then be cooled and coiled for future use. Although a generally simple process, there are limitations to creating filament through "pultrusion." One such limitation is that the process itself is very slow and it can take hours to turn a single plastic bottle into a relatively small quantity of filament (Joshi, 2012). The quality of the produced filament is lower than commercially available filament as it is hollow, requiring fine-tuning to effectively use in a 3D printer (Herman, 2022).

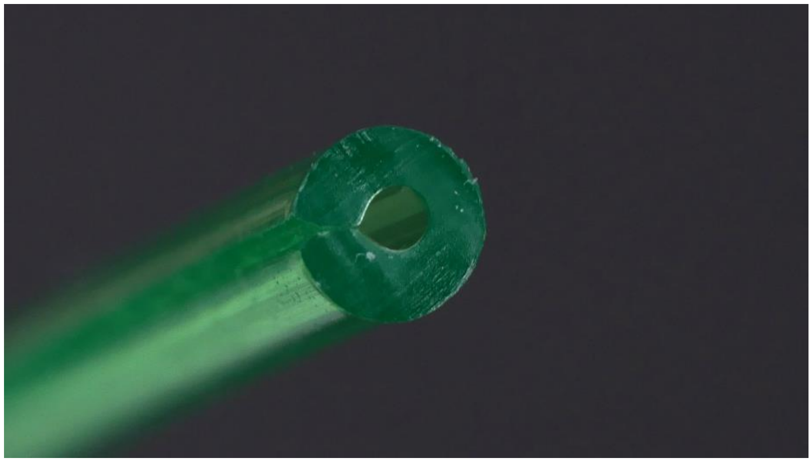

Figure 3: A cross section of pultruded filament

To avoid this issue, a pelletizer and extruder could be used. According to Woern (2018) pelletizers take 3D printer filament and shred it into more uniform pellets using a consistently spinning blade. Using the “pultrusion” method described previously, along with a pelletizer, it is possible to produced pellets of material uniform enough to be used in a traditional screw extruder. Rather than “pultruding” a specific diameter filament, a larger less accurate nozzle can be used to increase the speed at which bottles are “pultruded”. This filament will then be run into a pelletizer which will cut it into small uniform pieces. These pieces would have a much more consistent shape and would have a much higher flowability than shredded plastic. With a higher flowability, the pellets can then be used in the more consistent and reliable screw extruder assembly.Essentially, while pultrusion is a far simpler and more cost-effective way to produce filament, the low quality of the filament and the slow rate of production make it a poor choice to create a reliable source of filament for UNAM. A pure extruder system on the other hand is ideal for creating filament at a suitable pace and quality, but feeding shredded plastic into such a setup causes clogs and requires constant operator attention. Thus, the team pursued a hybrid approach. Increasing the speed of the pultrusion system destroyed the accuracy of the pultruded filament’s diameter, making it impossible to 3D print with. This downside did not matter though, as the team pelletized the pultruded filament into a highly flowable raw material that could be fed into a more accurate filament extrusion system.

2.3. Applications of 3D Printing in Medicine

The cost of complicated, patient-specific medical procedures and devices acts as a barrier to treatment for many patients. However, with the cost of 3D printing falling over the last decade, some medical professionals have begun using the technology in therapeutic and pre-surgical applications (Zang, 2017; Zastrow, 2020). Orthopedic trauma surgeons and researchers adopted the technology early in its development. Since the field of orthopedics deals with injuries related to large bone or tissue structures, each case of orthopedic trauma is different (Zang, 2017). Thus, 3D printing lends itself well to the field since it greatly simplifies the process of customization and personalization.

The adaptability of 3D printing in conjunction with preexisting medical scanning technology like CT (Computer Tomography) and CAT (Computerized Axial Tomography) scanning allows orthopedic surgeons to plan and execute operations with a better understanding of the patient's injuries and possible complications (Zang et.al., 2017). More recent developments in desktop 3D printing have opened the door for low-cost custom prosthetics for patients missing both structural members like full fingers and limbs, or soft members like ears and noses (Lal & Patralekh, 2018; Brown, 2003). While soft and structural prosthetics are not a novel idea, the immense cost reduction possible with 3D printing opens the door for more individuals to receive life changing medical treatment.

The early adoption of 3D printing in the orthopedic trauma sector combined the accurate modeling and digital scanning capabilities of MRI (Magnetic Resonance Imaging) and CAT scanning with the physicality of 3D printed specimen. Lal & Patralekh (2018) provide a comprehensive study of the use of 3D printing and rapid prototyping in presurgical planning and implant design throughout the late 2000s and early 2010s. Studies include using 3D scanned and printed models to reduce the need for prolonged radiation exposure during surgery, creating patient specific models of bone and muscle structures for surgeons to practice the placement of implants into a patient, and reducing unnecessary trauma to healthy tissue by analyzing the installation and impact of screws and other fasteners during surgery (Lal & Patralekh, 2018; Brown, 2003; Guarino et al., 2007). These research studies primarily see surgeons using MRI and CAT scanning technology common in hospitals to create digital copies of a patient's specific anatomy in the DICOM file format; converting these models to the stereolithography (STL) file format allow surgeons to 3D print areas of interest to better understand each patient's specific injury and prepare for complicated surgical procedures (Lal & Patralekh, 2018).

Using 3D printing to plan surgical procedures extends beyond surgeons practicing operations repeatedly, it also gives surgeons a chance to create more accurate reconstructions of limbs through 3D modeling of skin grafts. In one such case, Zang et al. (2017) uses 3D printed models to plan the reconstruction of thumbs. Using CT scans, Zang et al. first created a digital copy of a patient's healthy thumb in CAD software as an accurate reference for what the skin graft should look like after reconstruction. The team then modeled the donor material around the patient's big toe and matched the geometry of the reconstructed thumb to the donor site (Zang et al., 2017). The skin graft could then create an extremely accurate reconstruction of the thumb. A 3D printed model of the reconstructed thumb and skin grafted section of the big toe not only streamlined the presurgical timeline, but also helped patients understand their surgical procedure with physical 3D printed models. Using 3D printing, the study sought to "…eliminate adverse factors during surgery that are associated with the subjective experience of surgeons …, significantly shorten operation times and reduce the difficulty of operations" (Zang et al., 2017).

Presurgical planning and modeling via 3D printing primarily benefit doctors and surgeons preparing for complicated operations, but in the world of prosthetics, 3D printing has the chance to drastically decrease the cost of creating new custom prosthetic devices. Traditionally, creating molds for silicone prostheses is an expensive, time-consuming, and wasteful process, as a single custom mold can take months of work on specialized machines. Molds for traditional silicone molded protheses can cost upwards of $4,000 per prosthetic (He et al., 2014). He And colleagues explore the possibility of using common, inexpensive FDM 3D printers to create affordable molds for silicon prosthetics. One of their most fundamental challenges was the nature of FDM 3D printed parts themselves: when an object is FDM 3D printed it is constructed layer by layer, resulting in layer lines that give the finished model a rough, stepped texture. This surface roughness makes creating silicone molds nearly impossible with FDM 3D printing, as the silicone gets trapped within every sharp corner and step of the 3D printed part (All3DP, 2023). He et al. deliberately use ABS plastic in their 3D prints to combat this problem. In the presence of acetone fumes, ABS plastic slowly melts and flows, leaving the surface of ABS 3D prints smooth, free from layer lines, and suitable for mold making (All3DP, 2023). Combining inexpensive desktop 3D printers with ABS plastic allowed He et al. to create molds for custom silicone prostheses for under $30 USD per prosthetic, a significantly lower price.

The versatility and increasing accessibility of 3D printing give medical professionals the tools to make more informed decisions about their patients while also lowering the price for patients to receive life-changing care.

2.4. Benefits of 3D Printing in Medical Education

Human anatomy is a critical subject of study for medical professionals and current teaching methods depend heavily on the dissection of human cadavers: a standard teaching and learning practice since the seventeenth century (Radzi et al., 2022). Visual interactive models help students learn about the general structures and composition of the human body, providing the basics for understanding future clinical subjects; however, the use of dissection-based teaching in medical training programs is declining (Kazoka et al., 2021; McMenamin et al., 2014). Factors contributing to the decline include financial considerations, access to human cadavers, high maintenance of cadavers, and technological advancements (Radzi et al., 2022). Additionally, employing cadaveric materials in professional medical training has consistently been the subject of societal controversy (McMenamin et al., 2014).

Over the last twenty years, as 3D printing has become more affordable and widespread, the use of 3D printed anatomical models offers a potential alternative to the use of human cadaveric dissections in teaching. Using 3D printed models for educational purposes provides many new opportunities while teaching human anatomy. Contrary to cadaveric materials, which are subject to irregularity based on the health of the patient, 3D printed models are immune to these types of natural variation. By using 3D-printed models in lessons, students can study several variations, defects, and congenital diseases not only in one organ but also in complex organs or systems (Kazoka et al., 2021). The accuracy of the 3D-printed anatomical models can make it possible to see anatomical structures from angles otherwise impossible in lecture style dissections, improving the depth of knowledge gained by students (Kazoka et al., 2021). According to Kazoka et al., the use of 3D digital technologies at Riga Stradins University has led to great results in current students' level of knowledge, skills, as well as their performance in the Human Anatomy course. (Kazoka et al., 2021).

Despite the many benefits of implementing 3D-printed anatomical models in education, there are some financial and logistic limitations. For some schools, it might be a matter of financial concern as the upfront cost of 3D printers may be too large an investment for some. For others, the prohibitively expensive nature of anatomically accurate 3D models, especially those depicting specific chronic conditions, stands as a barrier to entry (McMenamin, 2014). As discussed earlier, the cost of materials also may prevent the consistent use of 3D printers in educational contexts. Furthermore, Kazoka et al. mentioned that more research needs to be performed to measure the effectiveness of the 3D model's incorporation into the anatomy teaching process and on the assessment of the level of knowledge and skills of students (Kazoka et al., 2021).

3. Methodology

In this section, the team will outline the methodology employed to achieve the project objectives. The team describes the target population and how we found study participants, the topics we discussed, and how we ensured rigor in our data collection and analysis. Also, ethical considerations, which guided the team's research, will be addressed.

3.1. Study Design

Over the course of seven weeks in Namibia, the team conducted a mixed-methods study combining qualitative interviews, tours of the dentistry and anatomy facilities, one focus group, and participant observations with UNAM staff and students. During this time, the team also carried out technical engineering work to create a machine to transform plastic waste into 3D printer filament. These methods provided a comprehensive understanding of the wants, needs, benefits, and shortcomings of the educational tools commonly used within UNAM, informing the design and function of the final filament extruder.

3.2. Study Population and Sampling Strategy

The team wanted to understand both the potential impact of 3D printing within the UNAM Medical School and its effects in medical practice. Thus, data was gathered from within the UNAM network of professors, staff, and students.

Based on preliminary research and the sponsor's advice, the team determined that the anatomy, dentistry, and occupational therapy departments were the most likely to benefit from incorporating 3D printing into their workflows: 1) The anatomy department heavily relies on numerous, high-fidelity anatomical models for teaching, making it an ideal application for 3D printing; 2) The dentistry department already utilize a suite of 3D scanning, modeling, and printing tools with the potential for FDM 3D printing integration; and 3) The occupational therapy department requires customized, patient-specific devices, meaning 3D printing could significantly benefit the department and the field as a whole.

Once the candidate departments were identified, the team compiled a list of relevant faculty members within UNAM as the sample population. Since the number of faculty members in the relevant departments was rather limited, the team attempted to recruit the entire population for interviews. As the team conducted more interviews, new candidates emerged. For example, a discussion with members of the anatomy department at UNAM led the team to interview a professor of histology from the University of Pretoria South Africa that was visiting UNAM the following week. This snowball approach also allowed the team to naturally collect data by conversing with students and staff in passing and participating in tours and showcases conducted by specific departments within UNAM (Johnson, 2014).

3.3. Recruitment Procedure

The recruitment efforts primarily utilized email communication. After the first in-person meeting with Dr. Wessels, the team received contact information for several professors and staff members working in each of the team’s three primary departments of interest. Dr. Wessels, the project sponsor, played a crucial role in facilitating communication throughout the process, encouraging his colleagues to engage with the study through email and in person. His extensive connections streamlined the recruitment process, resulting in a high response rate of 86 percent from potential participants while minimizing the time required to identify key stakeholders. After initial contact was made with potential participants, the team scheduled a date and time to meet somewhere at the Hage Geingob campus.

Recruitment for focus groups with students was approached differently than with the professors. Rather than direct outreach, the team used connections made at UNAM with the project sponsor and other professors interviewed to help recruit student volunteers. At the same time, by simply working from the UNAM campus, the team recruited students as they were coming to and from their classes. Interactions with students of occupational therapy not only helped the team recruit for focus groups, but also aided in creating a relaxed and friendly environment within the focus groups themselves. The team provided all potential participants with detailed information about the project, its goals, and participant privacy to ensure transparency and informed consent. Once the students agreed to participate in a focus group, the team either communicated through email or WhatsApp to plan a date and time to meet at the Hage Geingob campus.

3.4. Measures Assessed

The goal of this study was to collect sentiments and knowledge about 3D printing and its possible implementation in both educational and professional environments among UNAM students, faculty, and local medical practitioners. The team developed the interview and focus group questions into general topic guides with study-relevant questions related to themes such as ethics, teaching tools, and familiarity with 3D printing.

In addition to department specific topic guides, professors and technicians at the university were asked about their personal professional experience, how they currently teach their classes, and how they learned when they were studying in school. For interviews with professors, the team specifically followed up discussions on teaching tools with questions about familiarity with 3D printing and how 3D printing could bolster certain methods of teaching.

For the student population, the team collected responses to gain insight into the perception of 3D printing as both a medical and educational tool through focus groups. The questions were aimed to spark conversation between the students and allow conflicting or shared opinions and experiences to be seen. At UNAM, students begin clinical practice during their fourth year of school; as such, third year students and below were primarily questioned on the value of educational models and their learning experiences. The team asked fourth year students about their practical experience and the resources available to them during clinical practice. Due to the lack of responses from private healthcare professionals, data from fourth years students working in public clinics and hospitals helped the team understand common practices in those areas.

3.5. Data Collection Methods

Employing a hybrid approach, the team collected both quantitative and qualitative data from participants and through design and construction of the filament extrusion machine. Qualitative data collection primarily took the form of in-depth interviews with UNAM staff, while quantitative data principally took the form of design and sourcing considerations for the filament extrusion machine. The collection methods for each form of data are discussed in greater detail.

3.5.1. Qualitative Data Collection

In total, six in-depth interviews and one focus group were carried out with one follow-up interview and a series of WhatsApp discussions with members of perspective focus groups supplementing the data.

In-depth interviews with UNAM staff

The team used in-depth interviews for qualitative data collection from UNAM staff. A detailed table describing each interview participant's profession and the date and length of each interview can be found in Appendix D. Each interview with UNAM staff was conducted by all members of the team, where one group member took the lead. All interviews took place at the University of Namibia's Hage Geingob campus and were audio recorded, averaging about one hour long, with the longest being an hour and forty-five minutes, and the shortest being only thirty minutes.

Student Focus Group Discussions

The focus group with students took place in the Anatomy Museum at the UNAM Hage Geingob campus, lasting approximately one hour. The focus group conversations were audio recorded and saw the participation of five students. Unfortunately, one team member was not able to attend the focus group.

3.5.2. Engineering Methodology for 3D Printer Filament Production

The technical part of the IQP involved designing, sourcing, and modeling of a filament extrusion machine. Using a four-part process, the machine was designed to transform waste plastic bottles into usable 3D printer filament.

The team decided to implement a filament extruder to convert plastic pellets into a continuous strand of solid filament. This introduced an intermediary step that took the pultruded filament strand and cut it into uniform lengths. These pieces would have a much more consistent shape and would have a much higher flowability than shredded plastic. With a higher flowability, the pellets can then be used in the more consistent and reliable screw extruder assembly. This provided the material format required for the filament extruder to properly function and extrude consistent filament suitable for large prints (Woern, 2018).

Team Member Education

At the beginning of the project, bringing all team members up to speed on the inner workings of both 3D printers and 3D printer slicer software led to a series of "printer parties." These get-togethers allowed team members who had never touched a 3D printer before to assemble, modify, and tune a 3D printer from scratch. These events taught important technical skills and brought the team closer together, improving communication and building friendships. The skills learned during these parties informed design decisions with the filament extruder and contributed to more interesting and technically challenging conversations during interviews and focus groups.

3.6. Data Analysis

The team developed a code book in Excel, with separate tabs for each interview as shown in Figure 4, with a filled-out version in Appendix E. Codes were standardized across interviews for ease of comparison, however, some interviews contained themes in which others did not. All themes were considered regardless of how many participants addressed them. Each code was accompanied by relevant quotes, time stamps, explanations, and secondary codes, ensuring thorough analysis. To leverage diverse perspectives from research participants, team members individually coded interviews line by line, followed by group discussions. To facilitate analysis, the team consolidated each individual tab in Excel onto a single sheet as shown in Figure 5. This allowed the team to list quotes from different interviews in the same column alongside their corresponding shared code. Furthermore, color-coding was applied to each secondary code, facilitating the connection of key terms in the quotes to their respective secondary codes.

The method of qualitative coding used was a hybrid approach, which included both inductive and deductive coding (Jansen, 2023). The team developed predetermined codes from the research objectives but also considered codes that emerged during the data collection. For example, a major research objective was to explore the need for teaching models in medical education. So, the team decided to use this topic as one of the primary codes when undergoing qualitative analysis before any data collection began. However, there were some areas of research that the team did not consider until undergoing data collection. One example of this is ethical considerations. The significance of ethics in medical education was not anticipated, until it arose during multiple interviews with various population groups.

The primary codes were then broken down into secondary codes. This helped the team utilize more of the collected data. For example, one of the primary codes was ethical considerations. This topic was broken down into secondary codes including legal problems, gray areas, and medical community consensus. By pulling out smaller focus areas, the team was able to sort more of the data collected rather than what was on the surface.

Overall, through qualitative coding, the team looked for any major patterns and agreements among participants for any perspectives or ideas that stood out. All team members contributed to the coding process, picking apart interview transcripts and recording the emerging themes. Ideally all team members would code each interview so that important perspectives and themes are not missed out on, but due to time constraints at least two team members coded each interview. Starting with a small list of primary codes like “Teaching Models” and “Cost” the team branched out into secondary codes like “2D vs 3D” and “Government Funding” respectively.

Code	Raw Text	Line(s)	Notes/Explaination	Sub- Codes / Keywords
Teaching Models	"I don't know how much you know about **Histology**, but it's basically the tissue... But that's also very basic, and I want to say flat in terms of 3D printing" "So Histology, there is a three-dimensional aspect to it, which you still don't have to realize. I've not yet come across or have an idea how to apply 3D printing, or 3D physical image, or creating an image of the model from that."	23, 31 pt 1	- Notably refered to histology as "flat", suggesting that there isn't a need for 3D printed teaching models for this subject.	
	"**Anthropology** is where we really need to use it" "She studied or followed the guy there, Steve Simms...And the problem is now she needs to now teach people and so for that you need material." "So you want to show people the bone. And now try flying with human remains, which is not really easy. So the 3D printing makes that possible. So we micro CT scan a bunch of bones cases and now you can travel with it."	23, 30, 31, 33 pt 1	-Teaching people new skills/techniques related to physical antrhopology requires material as the human body is 3 dimensional, suggesting there is a need for 3D printed teaching models for this subject. - It's very difficult to travel with human bones, 3D printing makes it possible	Anthropology,Human Remains/Law
	"So for teaching and then we have valuable specimens...So you have one that's a very good textbook example, but now you give it to students, and then a year from now, The thing is, is useless."	49 pt 1	A major limitation of one of the current teaching methods, using real human specimens, is that they have lifespan issues and eventually become useless.	Traveling, Lifespan Issues, Reusability, Limitations
	"If I scan the (specimen) I have a 3D model that I can show the students on screen in three dimensions." ... "The textbook with paper and it's flat. There's No 3 dimensions to it." ... "To me, the 3D model that you have on screen which the student can take home (would bridge that gap)."	237-253 pt 1		Bridge the Gap,

Figure 4: Partial code book for Participant 1's interview.

Primary Code	Secondary Codes	Quotes	Participant
Ethics in Medical Education and 3D Printing in Medical Practice	Informed Consent Moral Gray Area	"Now we come to the process of if I take a photograph of that (cadaverous material), if I do research on that (its fine, but) , if I scan it and I make a 3D print, now it moves into an area where there isn't a legal precedent that says you're allowed to do this or that."	Participant 1
	Legal Precedent Biocompatibility	"The biggest challenge is really like managing consumables and because most if not all the stuff that we use actually have a shelf life and expiry date."..."Their material gets expired and then we're bordering on ethical guidelines."	Participant 2
	Community Consensus Cadaverous Material	"We had to apply for the Human Tissue Act to include the possibility to use cadavers that are unclaimed bodies from the mortuary."..."especially our population believe that people need to be buried."	Participant 4
	Religious/Cultural Conflict Occupational Justice Sourcing	"The general principle, I think is the moment (the specimen) is identifiable then it becomes a problem. ... I think everyone sort of agrees upon it. ... So if you have ... a case that got splashed in the media. This person was hacked to death with a machete to the head five times. And now you have a skull with a machete (through it). ... "Then everyone's going to know about it (who it was) .... (Then you have) 'Ohh I was in the front of the newspapers, you can't use me' and this poor sucker who didn't make the newspapers, I can use them."	Participant 1

Figure 5: Partial code book for cross-referencing and combining interview and focus group data.

3.7. Ethical Considerations

All participants were informed of the project details prior to consent. Confidentiality was always maintained, and the participant's name and other identifying information was excluded from any reports unless specific written consent was provided after the participant read the final version of the project paper. Those interviewed were assured that their involvement was completely voluntary.

Considering all team members have an engineering background, the study was validated with Dr. Wessels to ensure proper ethical considerations were followed. To ensure Dr. Wessels' good name and quality of work was upheld, the team updated him with working versions of the report. Thanks to Dr. Wessels' aid, the team was able to gain credibility and was connected to professors, technicians and students at the university, which greatly aided the process of the study.

3.8. Limitations

The team encountered some shortcomings during the recruitment process that limited the data available for the study. Initially, the team wanted to collect data from practicing occupational therapists and doctors working within or around the Windhoek area to investigate how 3D printing could improve local healthcare service. Compared to UNAM faculty, who are primarily concerned with teaching, medical practitioners could give insight into how they might incorporate 3D printing into current Namibian healthcare systems such as creating prosthetics, splints, and other simple devices. Acknowledging that 3D printing requires a unique set of skills often not afforded to medical doctors, the team also hoped to explore the feasibility of healthcare professionals adopting such a technology. The team planned to ask how formal education and exposure to 3D printing during university training may affect how certain clinicians carry out tasks related to personalized occupational therapy, orthopedic trauma, and prosthetic development.

The team compiled a list of medical practices within the greater Windhoek area. Of these, six practices were contacted via email, three of which were occupational therapy clinics, two were prosthetic companies, and one was a dentistry practice. Unfortunately, the team received no responses from any of the private medical facilities contacted.

The team also experienced some limitations around scheduling focus groups with UNAM students. Initially, the team planned to hold two focus groups: one with students from the occupational therapy department and another with students from the anatomy department.

Additional focus groups were also considered so the team could collect data from students in different class years. However, the team only managed to hold one focus group with five fourth-year occupational therapy students due to the students' schedules. The focus groups were to be held in the month of April, but many students had practicals and final examinations during this time, which severely limited their availability for a focus group. Thus, only the team only met with one focus group despite multiple attempts at a follow-up meeting and attempts to recruit another set of students.

Technical limitations including shipping, sourcing, and tooling all played a crucial role in the final design of the filament production setup. Without a proper source of funding from UNAM, the team used a $600 USD budget to source all parts for the project; fortunately, Namibian hardware stores in Windhoek stocked nearly all the supplies the team needed. Unfortunately, the import fees on parts the team could not source in Windhoek comprised roughly one-third of the final cost of the entire project. Further technical limitations resided in the limited tooling available at UNAM for construction. With access to basic woodworking and hand tools as well as a small lathe for metal working, several design changes took place to account for tooling limitations. With constrained time, tooling limitations forced some of the final mechanisms to have less than ideal craftsmanship, as team members rushed to meet deadlines.

4. Results

Combining inductive and deductive qualitative coding and quantitative data, the results of the study were sorted into sections most in line with the original objectives of the research: 1) to identify ethical considerations in medical education in Southern Africa; 2) to examine the need and use of models and other educational tools in medical education, and 3) to develop a functional filament production setup.

4.1. Objective 1: Identifying ethical considerations in medical education in Southern Africa

We examine ethical considerations inherent to 3D printing within anatomy, dentistry, and occupational therapy. Ethical considerations regarding 3D scanning and printing cadaverous materials come to the forefront in anatomy, while material biocompatibility and patient individuality come into question with regards to dentistry and occupational therapy respectively.

4.1.1. Ethics and Anatomy Education at UNAM

Anatomy education relies on cadaver dissections so students can understand the inner workings of the human body, but the use of cadavers in academic publications and in Southern Africa specifically can be a contentious issue.

One of the key ethical considerations anatomists must consider when working with cadavers and especially when publishing with results derived from dissection of cadavers is the presence of identifiable features. If a cadaver is identifiable in any way, then the findings from that dissection cannot be used for publication. In an interview with Participant 1, a professor of histology with a background in 3D printing and scanning technology, they described how pictures of cadavers with tattoos, non-contextualized appearances, or even easily recognizable faces are borderline unethical to publish with. In a more extreme example, Participant 1 explained how the remains of victims of fatal attacks may not be usable in academic publication.

> *"A case got splashed in the media. This person was hacked to death with a machete to the head five times. And now you have a skull with a machete (through it). ... Then everyone's going to know (who it was)".*

For students of forensic anatomy, these limitations can hinder their education. On one hand, anatomical specimens with violent injuries can reveal much about how the human body reacts to trauma, but as Participant 1 pointed out, the ethical dilemmas that arise from using such a specimen often prevent researchers from studying with these rare cases.

In the more common case of body donation, Participant 1 described how much of the controversy in terms of 3D scanning and printing stems from the fact that most donors do not specifically give consent for their cadaverous material to be replicated:

> *"So you have a bit of a gray area and I think this is again an example where your technology is ahead of where the law is... if I take a photograph of that (cadaver), if I do research on that (its fine, but) , if I scan it and I make a 3D print, now it moves into an area where there isn't a legal precedent that says you're allowed to do this or that".*

Participant 1 further explained how this 3D scanning controversy stems from the fact that participants rarely, if ever, give consent for their cadaverous material to be scanned or replicated. While traditional store-bought anatomical models are purposefully generic and do not contain any identifiable traces of their references, Participant 1 points out that an unmodified 3D scan of a cadaver would inevitably lead back to a specific individual.

Identifiability aside, the act of acquiring cadavers for research in the first place threatens the continued use of this traditional teaching method in Southern Africa. In an interview with Participant 4, a professor of anatomy at UNAM, they described how during and after the COVID-19 pandemic, acquiring cadavers in South Africa and Namibia has become significantly more difficult.

> *"You couldn't dissect any person that tested positive for COVID. Even if they died in a motor vehicle accident…they couldn't be donated so they couldn't be dissected. So we used to get a lot of donations from South Africa … [and] … we would have cadavers and then they were restricted. They (South Africa) don't have a lot of cadavers to do [dissections] so we end up with having that backlog."*

Participant 4 described how UNAM relies on imported cadavers from South Africa, where laws allow unclaimed bodies to be used for medical dissections, but the COVID-19 pandemic disrupted this relationship. Now, South African medical schools struggle to find enough cadavers for their programs, and according to Participant 4, UNAM is left with the "very difficult to dissect" specimens.

Addressing the challenge of obtaining cadavers for educational purposes, UNAM "applied for the Human Tissue Act," according to Participant 4, as a potential solution to the lack of cadavers. Participant 4 described how this would allow for the possibility to use cadavers that are unclaimed. However, Participant 4 lamented the fact that cultural traditions surrounding burial practices in Namibia prevented the passage of this act.

> *"There are a lot of cultural traditions around burials that we have to take into account. Especially our population believes that you cannot dissect. People need to be buried".*

Despite the cultural challenges, Participant 4 understood and respected the wishes and beliefs of those that voted on the bill, describing how the weak publicity for UNAM's body donation program serves as a root cause to the lack of available cadavers for the medical school.

The practice of cadaver dissection remains a stable of medical education, but the difficulty in procuring cadavers forces professors and researchers to pursue new means of studying these materials. The use of 3D scanning and 3D printing may increase the availability and study opportunities produced from cadaverous materials, but ethical gray areas regarding the legality and use of this scanning technology prevents progress on this front. The advent of COVID-19 broke down the cadaver lending program that existed between South Africa and Namibia; and now, cadaver shortages in South Africa prevents institutions like UNAM from receiving the cadavers needed to teach students.

4.1.2. Ethics in Dentistry: Material Science and Clinical Practice

With UNAM's department of dentistry, ethical questions arise about biocompatibility of materials with strict expiration dates. Dentistry, compared to anatomy and occupational therapy, requires extremely accurate molds and impressions for proper clinical work (upwards of +/- 0.005mm). As such, extremely accurate resin 3D printers are employed in the dentistry department's 3D printing lab. On a tour of the dentistry department with professors from the anatomy department, the team learned about the workflow and educational uses of the department's new Dentsply Sirona, Primeprint SLA resin 3D printers. Unlike FDM 3D printers, SLA 3D printers use a laser to cure layers of resin into a finished model. SLA printers achieve much higher resolution compared to FDM printers (Formlabs). For dentistry, these advanced tools are extremely valuable, improving the repeatability and accuracy of dental implants.

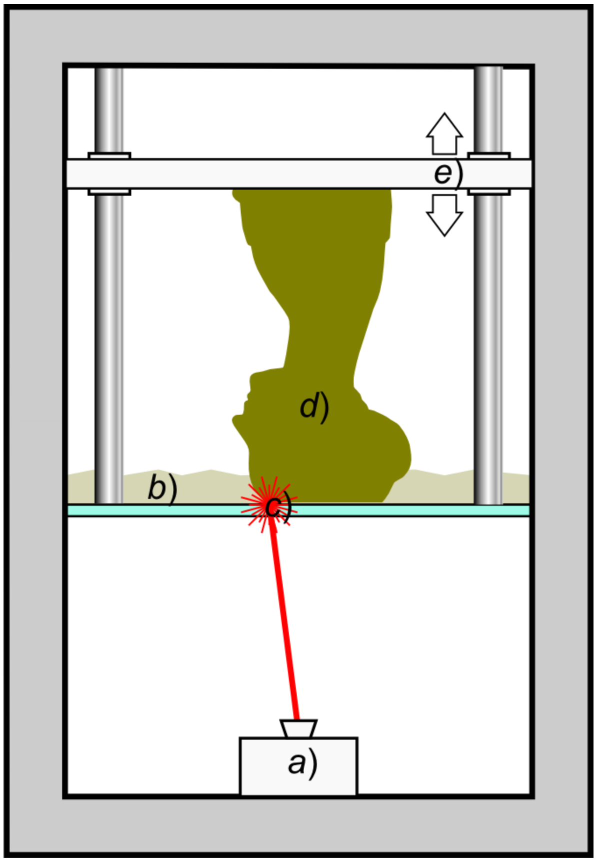

Figure 6: A schematic representation of inverted stereolithography; a light-emitting device a) (laser) selectively illuminates the bottom of a tank b) filled with a liquid photo-polymerizing resin; the solidified resin d) is progressively dragged up by a lifting platform e) (Scopigno et al., 2017)

Unfortunately, the Primeprint resin printers at UNAM come with strict limitations. The resin used to create custom impression trays for patients must be biocompatible, meaning it must be non-toxic and safe for the human body. In an interview with Participant 2, a dental technician working with the resin 3D printers at UNAM, the ethical frustrations of using biocompatible materials were laid bare:

> *"The biggest challenge is really like managing consumables and because most if not all the stuff that we use actually has a shelf life and expiry date...Their material gets expired and then we're bordering on ethical guidelines."*

While clear ethical lines exist, placing expired materials into a patient's body is clearly unethical. The fact that Participant 2 could not use the expired resin for any other purpose was a point of aggravation. The same company that makes the dental grade resin 3D printers also provides the only resin refills that work on those machines; as such, the company uses RF ID chips to tell when a specific case of resin passes the expiration date and forces the printer to not accept that case of material. In theory, this system completely prevents dentists from using material supposedly unfit for patients, but in practice this system denies the technicians and students at UNAM from using left over materials to learn more advanced 3D scanning, modeling, and printing skills that appear in contemporary dental practices more and more. An ethical dilemma appears, where using expired biocompatible materials is wrong, but wasting perfectly usable material for other purposes prevents dentistry students from learning new skills. These rules also affect the tight bottom line of the dentistry department as a whole.

4.1.3. Ethics in Occupational Therapy: Patient Individualism

At UNAM, the occupational therapy department focuses on the ethics of patient individuality, where the care of each patient must be tailored to their needs and daily activities. Participant 3, a professor of occupational therapy, explained how the individualized nature of occupational therapy makes treatment slow and tedious for professionals. This is also compounded by material shortages and understaffing problems common within public Namibian hospitals. The shortage of trained occupational therapists in hospitals becomes a problem as there are often more patients that need to be treated than there are occupational therapists to build assistive devices for them. Participant 3 described the processes of building assistive devices, saying that it can take up to three hours to make a single static splint: a simple structure that holds a patient's arm in place.

Some assistive devices do not need to be tailored specifically for the patient, but even those are in short supply. One participant from the focus group, a fourth-year occupational therapy student, mentioned that only a single plate guard (a device that attaches to the edge of a plate that helps the patient scoop food onto their utensil) existed within the entire Katatura State Hospital. Thus, the participant could not give the plate guard to the patient despite the need for the device.

The cost of materials also stands as a major barrier to patient care, as Participant 3 described the ethical dilemma of using materials to make fewer more effective devices or more less effective devices that could treat more people in a less useful manner.

> *"Say there's thermoplastic and I've got this much thermoplastic material to make the dynamic splint. I'll use this much and then there's one left to make a resting splint. But there's four patients that need it, and I can get 4 splinting material out of this to make four static splints. How do I measure?"*

Another issue that compounds the dilemma of who to treat first is that many patients must commute from remote regions for treatment, and sometimes the patient does not return for required follow-up treatment or maintenance. Specifically, Participant 3 explained:

> *"Sometimes a patient must use assistive device[s] for a certain period of time and then it should be taken away or a new one needs to be made. But when patients go back to the region, they don't always come back. So, what do I give them? Or if they can't come back for the maintenance?"*

When occupational therapists do not know if a patient will return for treatment, they cannot properly plan for all the necessary steps for healing. Participant 3 described this ethical dilemma where occupational therapy practitioners and students must learn to design assistive devices that are both easy to repair and resilient to long term use for people that may not return for treatment. While this provides a unique design challenge for students, in practice, the lack of material and human resources makes treating these patients from far off regions exceedingly difficult.

Taken as a whole, shortages in human and material resources within Namibian hospitals force occupational therapists to make difficult decisions on which patients receive the treatment they need. The stress of these shortages is compounded when patients from remote regions sometimes do not return for treatment: occupational therapists cannot predict if a patient needs an assistive device that will last for three months or three years.

4.2. Objective 2: Assessment of the Need for 3D Educational Aids

4.2.1. Tools of Anatomy Education

A recurring theme highlighted by four of the six participants emphasized the importance of three-dimensional learning in anatomy education. Moving from a flat two-dimensional textbook image to a cadaver is difficult for students not exposed to anatomical representations from different perspectives. Participant 4 revealed how valuable three-dimensional tools like anatomical models are for students:

> *"In anatomy, the three-dimensional aspect is very important...It makes a difference to them if they can physically touch everything. And they can try to mimic where the muscle is starting and where it's going to."*

Similarly, a student from the focus group discussed the difference between learning from traditional textbooks versus hands-on models, stressing the shortcomings of two-dimensional resources.

> *"You go to the lab, and they put a sticker on a specific part, either an organ or skull muscle and then they will ask you what that is. But, at home you are only studying from a textbook, not a 3D."*

Figure 7: Students using a plastic skeleton and tape to study muscle placement in the UNAM Anatomy Museum.

While the importance of 3D learning was acknowledged, three of the six interview participants emphasized the value of multi-modal approaches in anatomy education. Participant 4 noted the preference among students for varied learning modalities, while Participant 5, an anatomy technician, talked about how anatomical models and cadaver dissections help students contextualize the textbook diagrams, helping them better understand both the theoretical and hands on teaching materials. These perspectives show that while three-dimensional models offer unique benefits, they must complement rather than replace traditional teaching materials.

One of the major three-dimensional teaching methods currently used in anatomy education is cadaver dissections. The interviewed participants expressed concerns regarding the availability of cadavers, with Participant 5 expressing particular concern over the future of dissection programs.

> *"I think that is going to stop in a while. We are not going to get more cadavers from South Africa...If the law is maybe changed here and you can get it here. I don't foresee that in the next ten years."*

The skepticism expressed by multiple participants regarding the decreased availability of cadavers suggests the need for alternative teaching methods to address this gap. At the same time, the value of cadaverous dissections is undeniable: Participant 4 pointed out how cadaverous dissections force students to respect the human body and those that donate their bodies to science in a way that cannot be replicated with plastic models. Students from the focus group echoed this sentiment, with one student commenting on how cadaver dissections help students understand the three-dimensionality of the human body while humbling them in a way that helps prepare them to work on living patients.

> *"The cadaver you get, sort of the personalization is that you're taking something that's now this is no longer a plastic thing. This is a person and this reflects into myself."*

An emerging theme identified by the team was the notion of "bridging the gap" between theoretical knowledge and practical application in anatomy education. First introduced by Participant 1, this concept reflects the differences highlighted by four out of six interview participants between textbook representations and real-life anatomical structures. Students from the focus group understood this concept immediately, remarking on how textbook representations are often exaggerated for readability compared to the real structure.

> *"It doesn't look the same. The cadaver's brain is brown...and in the book it's color coded and doesn't match."*

Participant 4 touched on a key limitation of dissections and textbooks alike: accuracy. A prepared and dissected model will almost always be monochrome while textbook illustrations are often harshly color coded to aid students in learning anatomical theory. Neither representation is ever completely accurate in replicating the look or feel of a real, living, human structure. Participant 4 speaks on this discrepancy when describing teaching students the structure of the human heart.

> *"Looking at the 3D models and looking at the physical heart dissection itself, even, almost as far apart from a flat image to the 3D model because it doesn't, I mean it's not in color. The heart looks like it's one color. There's no, the arteries are not red. The veins are not blue."*

Recognizing the necessity for alternative teaching approaches, participants shared their individual suggestions regarding the integration of three-dimensional teaching models into anatomy education. Participant 1 proposed a system where students could "rent" a skeleton, allowing them to have a reference with them at home to illustrate and take notes with. Similarly, Participant 5 suggested using the resources in the Forge 3D lab to print a skeleton, or half a skeleton, for each student. Otherwise, students would only get the experience of working with these materials in their practicals. Further exploration revealed that multiple professors had access to some form of physical model of bones or a skeleton to take home when they were students. Participant 4 recalled,

> *"When I was at university, every group of students got a bag of bones...that made a huge difference. Especially with the teaching of the limbs. Knowing where the muscles are attached."*

While resources at UNAM may not support this practice, Participant 5 once again discussed leveraging the resources in the Forge 3D lab to mass produce anatomical models of skeletons for students to take home.

> *"What we also thought about is not actually to print the skeletons, but to print the mold. And then you can duplicate it but say for example you are going to print twenty humans it takes a while."*

Participant 5 noted the timeline challenges associated with 3D printing skeletons for many students: 3D printing of large parts can take upwards of 24hrs per part. Instead, using molds would enable the anatomy department to both use less expensive materials to make anatomical models (filament is much more expensive than plaster or resin) and create said anatomical models faster than any 3D printer.

These findings have significant implications for curriculum development and the use of educational models in anatomy education. They highlight the importance of adapting educational practices to address evolving challenges, such as the availability of cadavers. Furthermore, they stress the complex nature of anatomy education, highlighting the need for a multifaceted approach that integrates 3D learning, traditional resources, and innovative teaching methods.

4.2.2. Tradition and New Advancements in Dentistry Training

Within the dentistry department at UNAM students learn both the traditional method of taking impressions and waxing them to make dental implants, and contemporary scanning methods that incorporate 3D printing into the workflow. Challenges arise with balancing the two very different mediums for educational purposes. Participant 2 describes how the population spread of Namibia greatly impacts the teaching of dentistry. A largely rural country, Namibian dentists struggle to get patients to return for continued treatment.

> *"… the remoteness of the location and the patients being scattered it makes it hard economically to justify investing in (3D scanning technology), even though it would directly actually advantage the whole area … because it actually speeds up (making implants) and the margin of accuracy is better with the 3D scanning. So the trouble or the challenge that we have is we have than just sitting in the north, [many] rural areas [are] in the South."*

In a country where patients may only see a dentist once every few years for treatment, and access to 3D printing technology (and in some cases even electricity) can be difficult outside of major cities, dental students at UNAM need to know how to practice traditional dentistry. Educational aids in the UNAM dentistry department do not need a complete transition to new digital dentistry methods; instead, a mixed analog and digital system ensures that students are prepared to work in the myriad of environments and communities of Namibia.

The greatest educational tool for dentistry comes in the consumables necessary for lab work. Having access to accurate models of teeth that cut and look like real human teeth is vital for the program to continue. Unfortunately, the prohibitive cost of these model teeth holds back the program. With only a limited supply of model teeth and access to only a single German supplier, dental technicians like Participant 2 are searching for possible replacements that can be made in house. In particular, a plastic known as PEEK has shown promise due to having similar mechanical properties to real human teeth. Further research into PEEK will determine if the plastic can be suitably molded into accurate tooth models at a reasonable cost.

4.2.3. Occupational Therapy and Construction of Assistive Devices

Occupational therapy students undergo a unique curriculum tailored to the profession's need for personalized patient care. At UNAM, limited human and material resources in public hospitals inform the ways students are taught. Participant 3 discussed creating a project where students built assistive devices from common recyclable waste products.

> *"[The students]… fabricate assistive device out of waste. And they need to do it so that when they ever go work in the [remote] regions. They know that, OK, if I see a water bottle… it can be used for something because of the problems with resources at hospitals."*

This project prepares students that may work in remote regions of Namibia where they may need to improvise an assistive device due to lack of hospital resources. At the same time, students with such a heavy focus on in-situ resource utilization and not letting anything go to waste, Participant 3 and members of the focus group find value in using 3D printing for teaching and even clinical applications. Participant 3 discussed how 3D printing could speed up the timeline for creating assistive devices.

> *“So, with the 3D printer we would be able to get almost the basis - the generalized form. And then we adjust that thing to personalize it. ... "The basic structure would already save time and be very helpful for the patient.”*

Essentially, an easily modified baseline form for assistive devices like splints could speed up treatment as occupational therapists would not have to make an entire assistive device from scratch. A similar sentiment was shared in the focus group where occupational therapy students described how the rapid prototyping potential of 3D printing could enable the creation of specialized assistive devices. One student described designing and 3D printing a card holder for a patient with Parkinson’s disease to help them play poker. For niche cases like this, 3D printing opens the door for occupational therapy students to design and construct assistive devices without the resource limitations of public hospitals.

Overall, these discussions highlighted a critical need for more efficient and cost-effective assistive device construction methods in occupational therapy. Limited human and material resources along with the remote nature of many Namibian populations means that occupational therapy students learn how to use resources in their immediate environments to create assistive devices. At the same time, students and professors see opportunity in using 3D printing technology to enhance individualized care that occupational therapy offers to patients.

4.2.4. Funding Constraints and Public Universities in Southern Africa

All three departments the team interviewed at UNAM shared one key sentiment: the lack of funding for public institutions serves as a major barrier to procuring necessary resources. In every interview the team conducted, the participant always mentioned the lack of funding that plagues UNAM. Departments across UNAM rely on grants from foreign companies to grow their resources, but without internal funding for common consumables those new resources become underutilized. The Forge 3D lab is a great example of this cycle, where Dirisana+ granted UNAM the funds to purchase 3D printers, but without an internal budget set aside for the consumable filament the printers cannot run. There exists a complete lack of funding to expand pre-existing programs at UNAM apart from strictly necessary operational costs.

Regardless of the department, interviews with professors and technicians working at UNAM always mentioned the need for an independent revenue stream to supplement the cost of consumables. Participants 3 discussed a way for students to build and rent out personalized assistive devices to those that need them for short periods of time. Participant 4 and Participant 5 mention using the 3D printers in the Forge 3D lab to print models for local medical practices that may want them, and Participant 2 even discussed opening a dentistry clinic within UNAM that would take paying customers from the surrounding Windhoek area.

4.3. Objective 3: Development of a Filament Production Setup

Over the course of the first seven weeks of this project in Worcester and into the first four weeks of progress in Windhoek, the team designed a filament production setup meant to convert common plastic water bottle waste into usable 3D printer filament. This section shall describe both the engineering justifications made during the design processes and the resulting mechanical and electrical designs for the final machines.

4.3.1. Mechanical Design

The team designed and sourced parts for three unique mechanical systems: a bottle cutter capable of spiralizing a range of common bottles into a consistent strand of plastic, a spool winder to collect the plastic from the pultrusion setup, and a filament extruder capable of converting pellets of PET plastic into consistent strands of filament. To produce a minimum viable product within the given time range of seven weeks in Windhoek, non-essential components like a device to quickly cut the pultruded plastic into pellets were forgone in favor of chopping the plastic strands into pellets by hand. By the end of the time in Windhoek, about 80% of the total machine was completed, with much of the electrical, programming, and tuning work purposefully undone as it could be accomplished remotely.

Bottle cutter design: Figure 8 showcases the first revision for the bottle cutter design. To create a robust and repairable system, the bottle cutter relied on readily available metric hardware that simply drops in place within a 3D printed base. Different sized spacers and clamps hold a common utility knife blade at a fixed height to ensure the spiralized plastic comes out at a consistent height. As shown in Figure 10, the floor of the base is designed to hold three Namibian one-dollar coins. The coins provide a metal surface over which the PET strand will slide, so the material interaction is PET on metal rather than PET on PETG. This ensures that even with years of use, the bottom 3D printed plastic base will not wear away.

Once assembled, the first bottle cutter design spiralized the PET bottles, but the bottle had to be manually pushed down. Due to time constraints, the team decided to utilize a new existing design from an online source as shown in Figure 8, modifying the files to include the Namibian coins at the base. This design is similar to the first revision design, but it is more suitable for cutting PET bottles without having to hold down the bottle by hand.

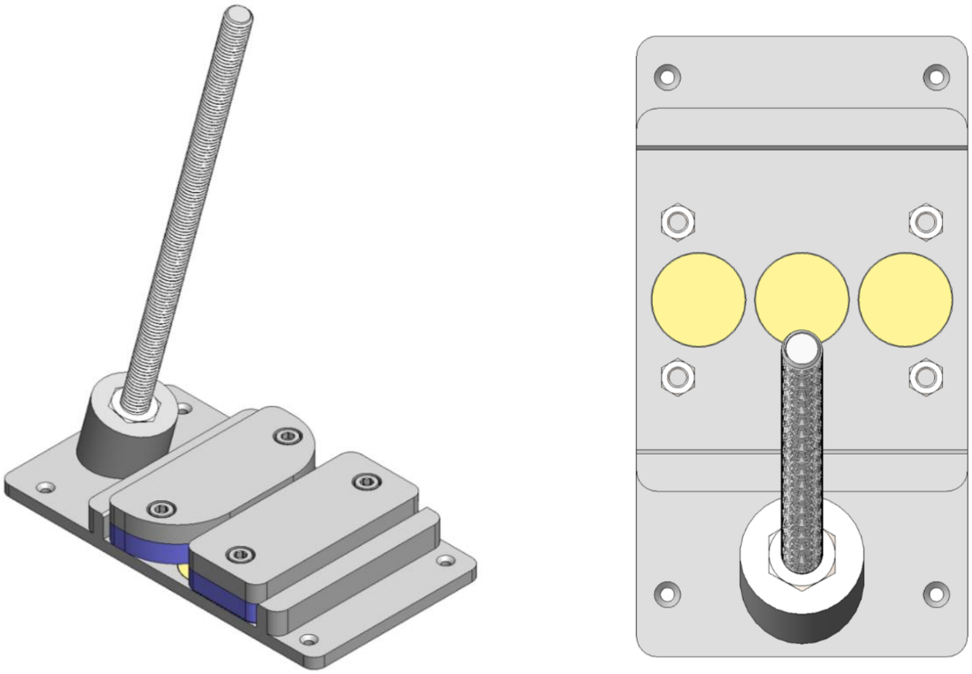

Figure 8: Orthographic (Left) and Top-down (Right) view of bottle cutter assembly.

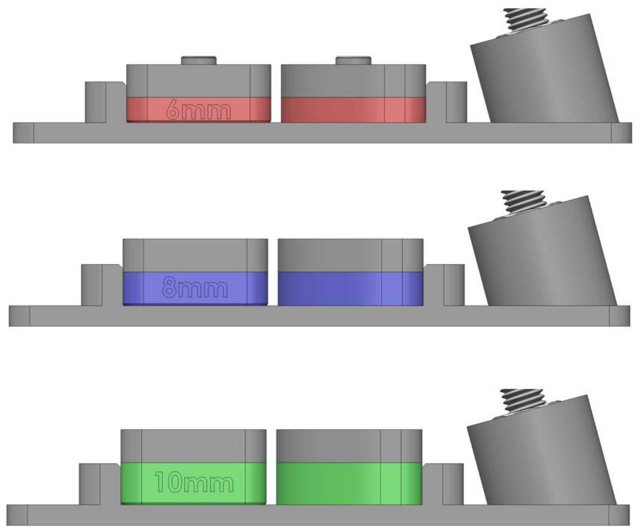

Figure 10: Different sized spacers for bottle cutter.

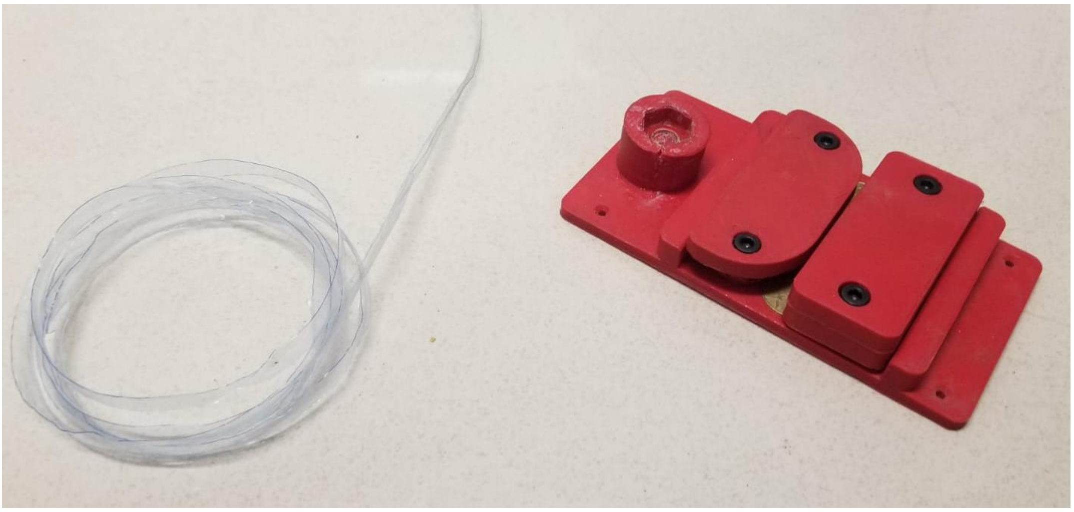

Figure 12: Rev. 1 of bottle cutter after destructive testing with spiralized bottle.

Figure 11: Existing bottle cutter updated design (Batek, 2023).

Filament winder design: Figures 12 and 13 showcase the final design of the filament winder assembly. This structure both spools the finished filament produced by the extruder, but it also automatically winds the filament in a tangle-free manner. The winder itself relies on a combination of 3D printed parts, COTS hardware, and a wooden stand. The use of wood lowers the cost of lager components and makes modifications and repairs easier for future users. A NEMA 17 stepper motor will drive the filament winder and pull the molten plastic from the nozzle of the filament extruder.

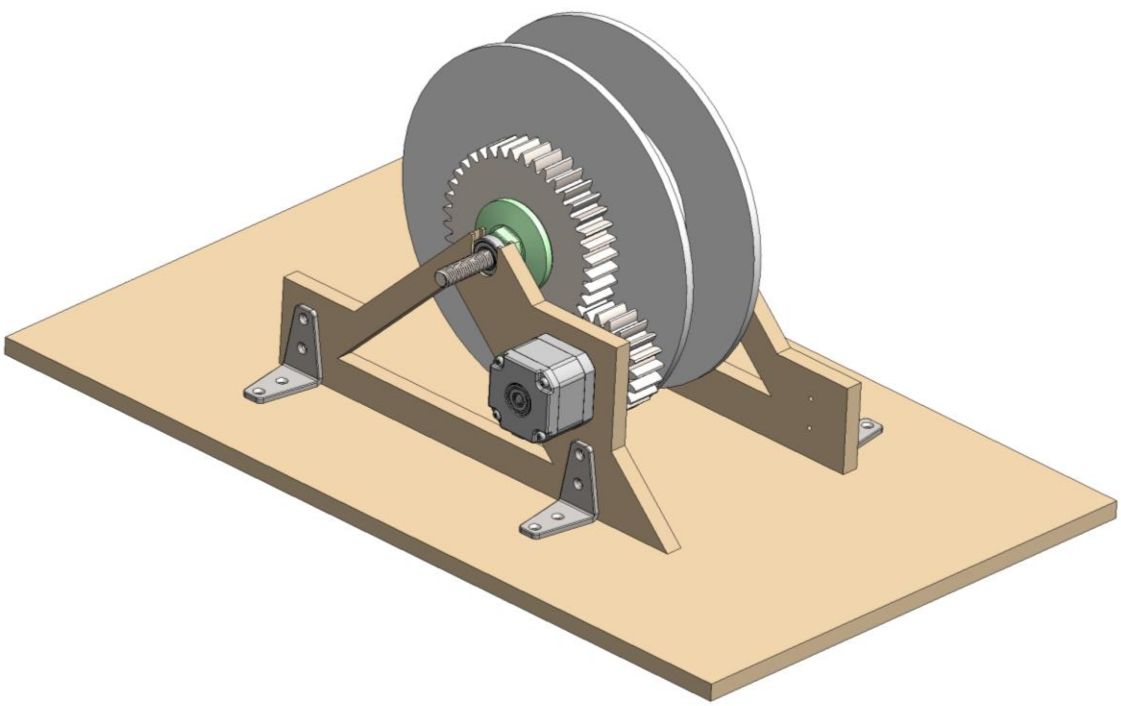

Figure 13: Orthographic view of filament winder assembly.

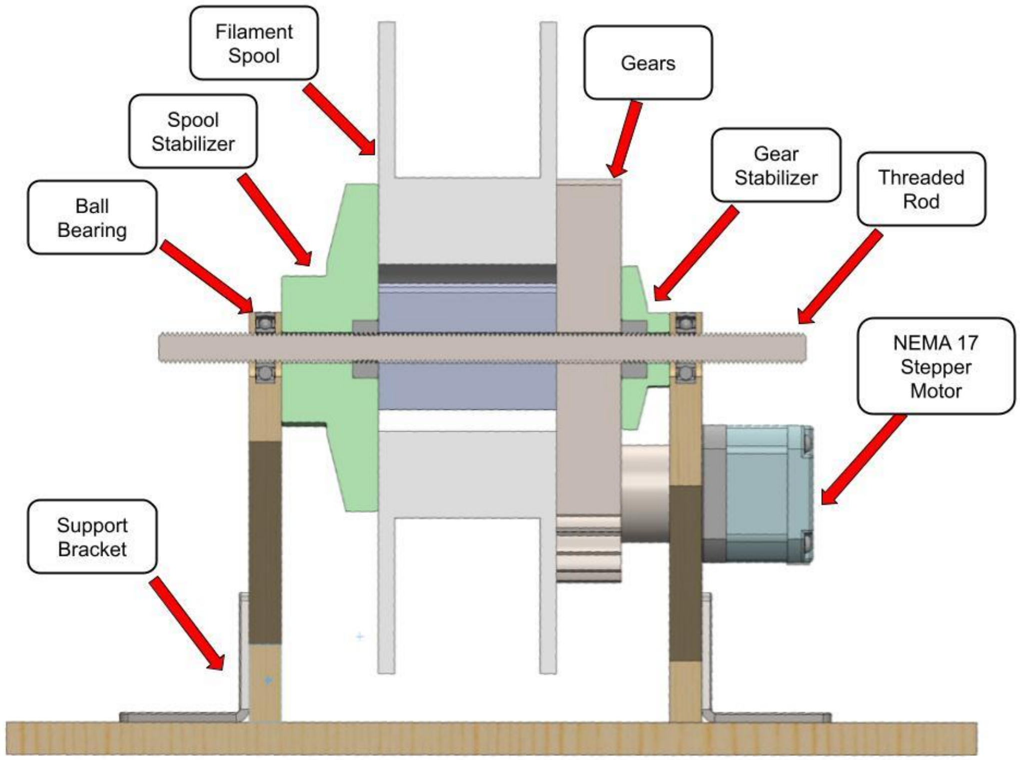

Figure 14: Cross section view of filament winder assembly.

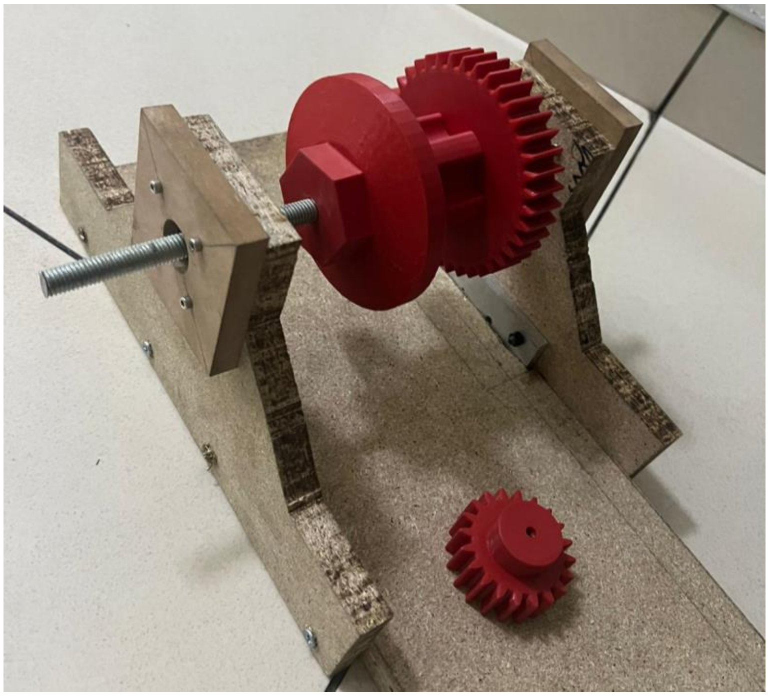

Figure 15: Prototype filament winder during construction.

Filament extruder design: Figures 14 and 15 showcase the final design of the filament extruder. This device will transform the pelletized pultruded plastic into a continuous strand of filament by feeding the plastic into an auger that then moves the material through a heated chamber and through a nozzle. The heated chamber of the filament extruder uses two heater cartridges and a pair of thermometers that feed into a control system that will use an error correction algorithm to keep the temperature consistent. The central auger is turned using a NEMA 23 stepper motor, and an additional feedback controller is used to adjust the consistency of the filament diameter. Almost all components in the filament extruder were designed to be COTS or easily replaceable. Since this system will be exposed to relatively high temperatures (230°C) it is good practice to make most parts easily replaceable and inexpensive. The few custom parts for this assembly are either machined from brass and aluminum or are placed further away from the heated elements of the extruder.

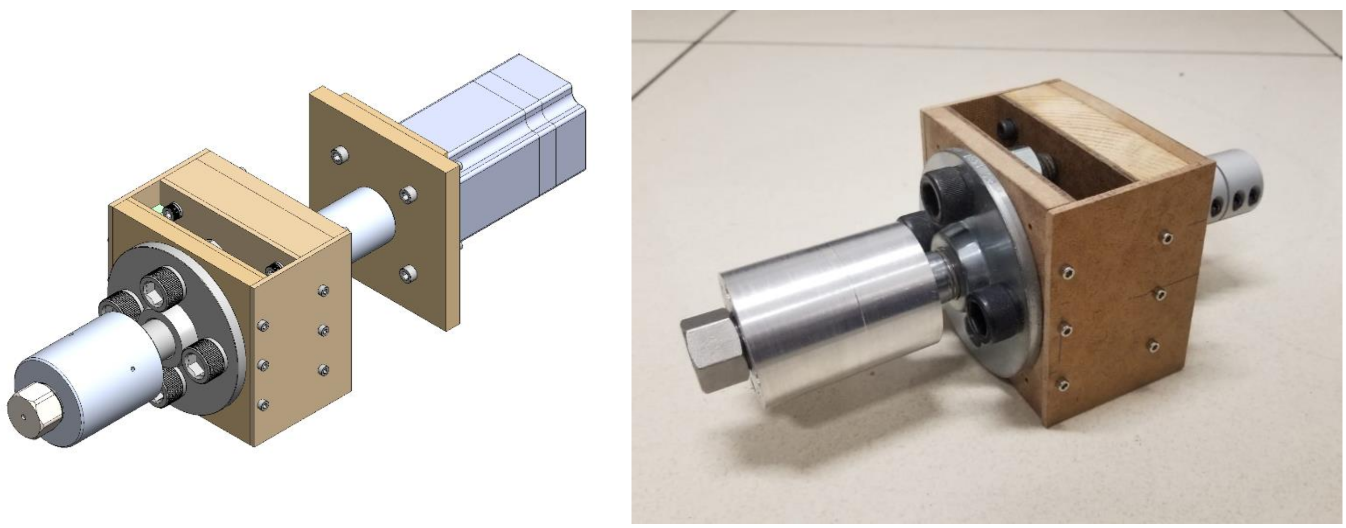

Figure 16: Orthographic view of filament extruder assembly in CAD (Left) and after assembly (Right).

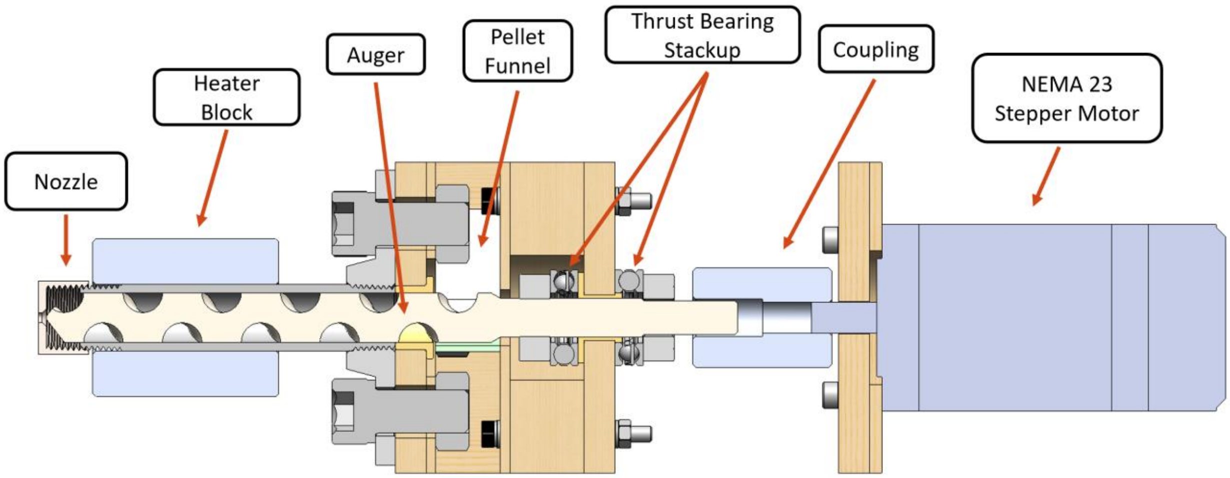

Figure 17: Cross sectional view of filament extruder assembly with relevant labels.

4.3.2. Electronics Design

To ensure the performance and reliability of the filament extruder, the team developed a custom solution to the electronics, software, and algorithms that control the device. The team's research found that most hobbyist-designed extruders used rather crude control systems and were not very intuitive or user-oriented. Thus, the team chose to design and program a robust, control system specific to the needs of this device and its users.

The team modeled the electronics system after the Lyman Extruder, a hobbyist filament extruder, and the Akabot, a filament extruder designed by a team of University of Santa Clara students. However, the team improved upon the Lyman Extruder and Akabot in three main aspects: a centralized controller, better motors, and a simple user interface. Instead of several independent controllers as used in the Lyman Extruder, the team opted to use a commercially available 3D printer motherboard as the central controller for the machine. The team ultimately chose the BIGTREETECH SKR Pico V1.0 as the motherboard for the extruder due to its cost, programming framework support, and capabilities.

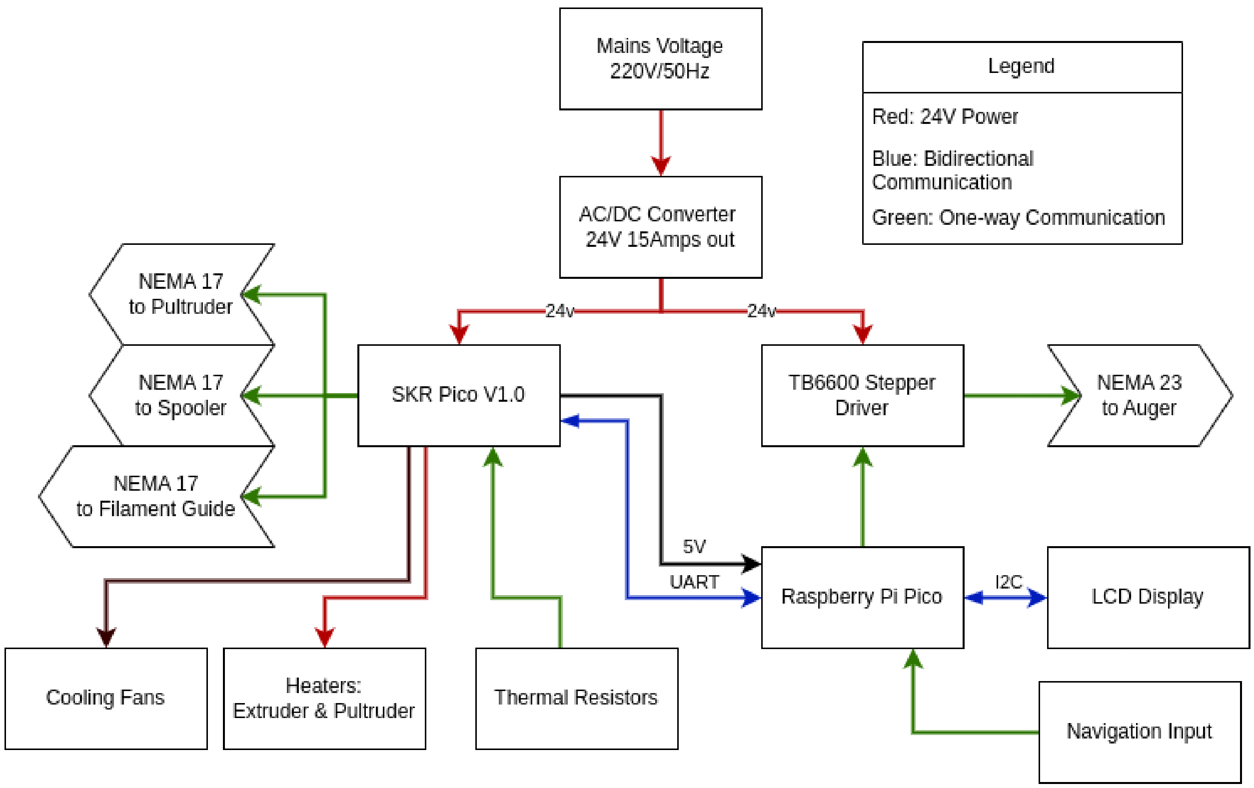

Figure 19: A system diagram of the electronics for the filament extruder

The SKR Pico allows for a coordinated calculation of the PID algorithms that control the extruder. As an overview, proportional, integral, derivative (PID) control is the most used control algorithm in industrial applications; it is a closed-loop system, meaning it uses measured feedback from the system to correct control errors (MathWorks). Essentially, this means the machine can change its speed to adjust the diameter of the filament in real time. These PID algorithms rely on three tunable coefficients that respond to measured system feedback and yield a corrected output signal. These coefficients are rather volatile, and small changes in their values may result in massive changes in the output signal's accuracy. Since the Lyman Extruder and the AkaBot manually set PID controllers for turning temperature control and motor speeds, these devices' PID control is prone to human error and is unoptimized. However, the SKR Pico permits autotuning the PID controller by performing an automated calibration procedure, precisely tuning the algorithm for optimal performance.

The team also replaced the brushed DC motors present in both designs with stepper motors. Compared to brushed DC motors, steppers have significantly more positional accuracy and very high torque at low speeds (Thomas Motors). This is ideal for driving the auger since it requires high torque at low speeds, and it avoids the gear reduction needed when using DC motors. The SKR Pico also has built-in circuitry to control stepper motors, removing the need for additional motor controllers for the DC motors.

Finally, the team implemented a simple user interface for controlling the device. To do this, the motherboard connects to an auxiliary Raspberry Pi Pico that hosts the menu system. The user navigates the menus using a rotary encoder and a button to select options and set parameters such as the extruder temperature, flow rate, and run PID tuning. The menus and information are all displayed on an LCD screen on the device.

In all, the mechanical and electrical design complement each other in functionality and repairability. With all parts being easily replaced, this prototype system is designed as a proof of concept meant to help the Forge 3D lab eventually develop a robust system for continuous filament production. Considering the materials used to build the extruder and the heat fluctuations inherent to a system like this, it is likely that the mechanical systems will require consistent upkeep while the electronics and software can be reused with future iterations. At the time of writing, all materials had been sourced and mechanical testing of the filament winder and filament extruder were underway. The mechanical components were almost entirely complete, with only a few minor integrations with some of the electronic components remaining.

Following the completion of the mechanical components, programming and electrical work will occur remotely with team members working with UNAM staff to upload, test, and tune the machines. With most of the wiring completed for the electronics, team members plan to maintain communication with technicians through WhatsApp or email, assisting in updating code, wiring components, and fixing any mechanical problems that may arise. If Forge 3D Lab staff express interest, several of the team members offered to design a second iteration of the filament production setup, this time with a better understanding of the limitations and requirements of working in Namibia.

5. Discussion

5.1. The main aim of this IQP was build a machine to transform waste plastic into useable 3D printer filament for the Forged 3D Lab at the University of Namibia. The team therefore explored the possible uses of 3D printing across the medical school campus, interviewing professors and speaking with students. The team's findings revealed department-specific needs, with a common thread of ethics, a clear demand for educational models and funding constraints. In the anatomy department, participants emphasized the need for more 3D anatomical models due to the prohibitive cost of traditional models and the challenges in accessing cadavers. In dentistry, advanced 3D printing and scanning technologies are utilized, but limitations exist in the accuracy and biocompatibility of FDM 3D printing materials for oral applications. In occupational therapy, there is a demand for educational models and potential applications of 3D printing for splints and devices to enhance learning and patient care. In turn, recycling waste plastic into 3D printing filament emerges as a promising solution to funding and ethical concerns, offering UNAM students' greater access to educational resources. Anatomy Education, Cadavers, and Anatomical Models

Research in anatomy education has explored the ethical considerations of cadaver dissections in parallel with their usefulness as educational tools. In a paper published by Hasan, the author points out the historical controversy surrounding the practice of cadaver dissection yet also acknowledging the invaluable firsthand morphological insights it provides (Hasan, 2011). In Southern Africa in particular, cultural traditions related to burial prevent many from donating their bodies, and in countries like South Africa political mistrust, a remnant of the apartheid era, prevents black Africans from donating their bodies to programs that historically exploited black bodies for the exclusive education of white students (Kramer, 2024). In most Southern African countries, medical schools get their cadavers from unclaimed bodies, but COVID-19 shrank the supply of cadavers available for dissections around the world, necessitating research into alternative educational methods that offer comparable benefits (Kramer, 2024).

One alternative to cadaver dissections is greater utilization of anatomical models in undergraduate anatomy education. When speaking with both professors and students at UNAM, there existed a near universal need for more three-dimensional teaching materials. Using the resources in the Forge 3D lab and a renewable source of filament such as the one produced from the team-designed filament extruder, each student could have their own 3D printed set of inexpensive anatomical models that they could illustrate, take apart, and mark with landmark features. Yuen (2020) highlights the effectiveness of this approach, citing a study conducted in the United Kingdom at Brighton and Sussex Medical School where 3D-printed organ models were utilized for teaching purposes. The study found that students who received instruction via 3D models outperformed their peers who were taught using traditional 2D methods (Yuen, 2020). A similar study by McMenamin (2023) presents evidence from Monash University, Australia, where 3D printed replicas of human remains were employed as alternatives to cadaver dissections. The study revealed that students exposed to 3D prints achieved higher post-test scores compared to those relying solely on cadaver dissections (McMenamin, 2023). The results of both of these studies, similar to the sentiments gathered in this study, suggest that 3D printing could make mass produced anatomical models an intermediate tool between two-dimensional textbook diagrams and cadaver dissections.

Yuen (2020) also highlights the limitations of 3D printing towards anatomy education. Yuen (2020) asserts that the primary concern regarding 3D-printed models revolves around their accuracy compared to human anatomy. Without post-processing, 3D-printed models lack the proper coloration and texture found in cadavers or living tissues (Yuen 2020), a sentiment shared by the student participants from the focus group and Participant 4. Accuracy issues regarding 3D printed models may prevent such tools from being useful educational aids, but as Participant 4 explained, some parts of the human body are more conducive to 3D printing. They described how, for identifying structures of the heart, for example, 3D models aren't as helpful as cadavers. However, Participant 4 emphasized the potential of 3D printed models of bones, allowing students to visualize the structure and relation to muscle tissue.

Not every anatomical model can or should be made using 3D printing. In UNAM specifically, 3D printing serves as a potential tool to increase access to more aspects of multimodal anatomical learning. Professors and students must experiment with the types of anatomical models that they find the most educationally valuable. Both Participant 4 and Yuen (2020) agree that a great place to start with 3D printed models is osteology: the study of bones. When using models of bones students are less concerned about coloration and detail but are more focused on the placement of muscles and the movement of joints (Yuen, 2020). While professors and students determine which anatomical models are the best for education, anatomists and governments worldwide must decide on the ethics of using digitized cadaverous information.

Procuring accurate 3D scans of human specimens offers a unique new challenge for anatomists worldwide, as new laws fail to meet the breakneck pace of technology. In a study by Lottering (2022), the author cites concern among Southern African anatomists that a body donor's informed consent may not account for the digital recreation of that individual's body, whether it be 3D scans, 3D prints, CT scans, or even digital photographs. Despite the lack of legal precedent in Southern African countries, seventy percent of the forty-six respondents thought that specific consent must be given by the donor for any creation or distribution of digital copies of their remains (Lottering, 2022). This moral gray area described specifically by Participants 1 and 4 is clearly reflected in Lottering's (2022) study, where a lack of uniform legal and ethical precedent makes it difficult for professors to move forward with 3D printing as an educational tool. While the ethical ramifications of using cadavers imported from other countries may not be an issue with 3D printing anatomical models, anatomists must come to a consensus on when it is ethical to create and distribute digital copies of cadaverous materials. This ethical conundrum cannot be handled by a single government or even region, as the easily shareable nature of digital files makes it easier than ever for cadaverous materials to be shared and used around the world.

4.4. Occupational Therapy and Occupational Justice

Occupational therapists strive to achieve occupational justice with their patients, themselves, and their communities. Occupational justice refers to a patient's ability to engage in the meaningful activities that they are expected or want to do considering their circumstances (Whiteford, 2022). In this respect, occupational injustice occurs when a person cannot participate in daily activities or occupations typical to their community due to legislation, cultural stigma, personal disability, or historically entrenched injustice (Whiteford, 2022).

In Namibia, people living with disabilities can find it difficult to achieve occupational justice within their communities because of commonly held cultural stigmas. In a study on commonly held beliefs regarding the cause of disability in Namibia, Haihambo and Lightfoot (2010) describe how the cause of disability can be attributed to everything from supernatural causes like witchcraft to improper relations by the mother of a disabled child. In some regions, people may be referred to by their disability rather than their actual name, and some families even choose to keep their disabled family members from the public eye out of shame; this can mean shunning them to the back corners of a homestead or simply not mentioning them to others in the community (Haihambo; Lightfoot, 2010).

Another study by Chichaya et.al. (2018) examined how outdated Namibian policies proliferate occupational injustice, contributing to lack of transportation services, feelings of isolation, and occupational deprivation for people with disabilities. These studies exemplify the uphill battle that occupational therapists in Namibia fight to work towards occupational justice for their patients.

Unfortunately for UNAM, these factors sometimes significantly hinder the abilities of the occupational therapy department. Occupational therapists like Participant 3 may not have the means to change social stigmas or impact political discourse, but the work done to help patients live their day to day lives with assistive devices and physical therapies enables Namibians living with disabilities to challenge and gradually change cultural attitudes towards disability. As more people are able to engage with the occupations of their choosing with the help of assistive devices, cultural perceptions of disability shift away from taboo. The advancement of occupational therapy at UNAM and the availably of affordable assistive devices actively pushes Namibian policies and culture towards more ubiquitous occupational justice.

5.2. Recycling Waste Plastics for 3D Printing

Aside from the Lyman Extruder, the team found several published instances of other groups designing, analyzing, and creating devices that convert waste plastic into 3D printer filament.

While all these devices aimed to reduce the cost of obtaining reliable filament, some were specifically intended to be deployed in communities where filament is hard to obtain.

5.2.1. The Akabot

The Akabot was the senior thesis of several mechanical engineering students at Santa Clara University. It was a filament extrusion machine that attempted to waste plastic into filament for a company in Kampala, Uganda since importing filament was unsustainable. The company, Village Energy, manufactured solar lanterns for rural households in Uganda to reduce reliance on kerosene lanterns. Village Energy chose to 3D print the housing for their lanterns since it was a low-cost manufacturing method, leading to the Akabot to provide the plastic required to print these housings (Albi et al., 2014).

The device specialized in converting PET water bottles into filament rather than other forms of waste plastic or virgin pellet material. Thus, the team's report went into detail about their project, including the mathematical models, hand calculations, decision matrices, and simulation results that lead to their finalized design.

The team successfully created a filament extrusion device with an approximate cost of $500 USD. The team also performed a cost-benefit analysis that compared the cost of the device to the price of importing filament with break-even after five months. Unfortunately, their final product was incomplete and was not in use by the end of the study (Albi et al., 2014). However, their work provides outstanding reference material for designing a filament extruder device.

5.2.2. The Recyclebot

The Recyclebot was a filament extrusion device designed to be affordable, easy to build, and repairable. The authors intended it to be an open-source research platform, and many of its components are 3D printed to reduce the cost of the machine. The device costs approximately $700 USD and reduces the price of filament to roughly 2.5 cents USD per kilogram produced. The authors suggested using a commercial paper shredder for producing the pelletized material for the extruder input; however, the device reports a filament diameter tolerance of ±4.6%. For 1.75mm diameter, this yields a maximum and minimum diameter of 1.83mm and 1.67mm respectively. This massive variance is likely due to poor flowability of the input material (Woern, 2018).

The authors produced a very robust design, and they explain all manufacturing and assembly steps. The paper also provides all the CAD models and software for the device and areas for improvement and future work. Despite the thorough design, the software controlling the machine is very limited. It does not have PID control, calibration procedures, or functional filament diameter monitoring (Woern, 2018).

5.2.3. The Recreator3D Pultruder

Recreator3D is a series of low-cost pultrusion devices aimed at the hobbyist community, and multiple iterations of the device are in development. One of these models, the Recreator3D Mk5, was specifically designed to utilize and convert components from an Ender3 3D printer, which is one of the most popular and cheapest 3D printers (Recreator3d). This reduced the burden of purchasing many specialty components, and it requires no changes to the printer's software. This made the device significantly easier to assemble and operate (Woern et al., 2018).

The Recreator3D is one of the most popular pultruder designs. Both Hackaday and MAKE Magazine featured the device, and several popular YouTube channels such as CNC Kitchen and

Toms3D have posted videos promoting the product. The project is also very well supported, with active development within its Discord and Facebook communities.

5.3. Impact of 3D Printing on Medical Education at UNAM

3D printing has the potential to bolster pre-existing medical education tools and create new opportunities for learning at UNAM, offering a unique chance to avoid the funding and ethical limitations that prevent students from utilizing all tools at their disposal.

With strict funding limitations and a short supply of cadavers, 3D printing has the potential to "bridge the gap" that exists between medical theory and clinical practice at UNAM. The construction of the filament extruder is both indicative of the greater problems at UNAM while also representing the ways faculty and students continue to persevere. A consistent and free supply of recycled filament could change the way professors and students study medicine at UNAM: anatomy students could take home 3D printed anatomical models instead of sharing a single commercially purchased model with a dozen other students, dentistry students could print what would otherwise be costly consumables, and occupational therapy students could design, and 3D print new and innovative assistive devices for testing.

With a renewable and practically free supply of filament, anatomy students could each receive a set of anatomical models to study on. Students could draw, color, and modify their models depending on what they are studying. This technique of allowing students to take home models mirrors the old practice of giving medical students a bag of human bones (Participant 4 and 1) to study with but without the ethical headache. For anatomical models that require more detail, specific textures, or need to be multi-part, the use of 3D printed molds smoothed with acetone or simple mode-podge could both allow for the distribution of these more complex models while creating an easy way to mass produce models with reusable molds. Importantly, mass produced anatomical models should not replace multi-modal medical learning. Three out of four participants in the anatomy department discussed the value in using multiple teaching tools, combining multiple mediums like textbook study, cadaver dissection, and anatomical model reference are necessary for a well-rounded anatomy education.

The next generation of dentistry tools heavily incorporate high accuracy resin 3D printing into the workflow; as such, FDM 3D printing has few applications within dentistry simple due to the accuracy requirements of dental work: as one of our participants explained, sometimes a tolerance of only five microns must be kept so an implant does not cause a patient discomfort. Accuracy aside, most FDM 3D printer materials are not biocompatible and those that are biocompatible are prohibitively expensive (Dentsply Sirona, 2022). Using recycled materials for dentistry creates unnecessary risk for patients, but that does not mean that unused and expired materials need to be thrown away.

Leftover resin and even cheaper resin on cheaper resin 3D printers could offer students a way to learn about preparing and printing scans of patients' mouths. Unfortunately, the dentistry grade printers used at UNAM utilize proprietary resins, and the printer itself will not allow a technician to use an expired resin. While this makes sense for protecting patients, in an academic setting this limitation leads to wasted materials and wasted teaching opportunities. While greater access to resin 3D printing technology bolsters the skillset of dentistry students, the ubiquitous lack of funding felt at UNAM prevents the department from expanding its teaching capabilities.

This universal lack of funding shows itself within the occupational therapy department where the patient specific nature of OT brings about a slew of funding related limitations. Occupational therapy as a discipline focuses primarily on patient specific care: where each patient receives treatment specific to their injury or ailment. With 3D printing, students could design, model, and print their own custom assistive devices. This not only gives students the freedom to modify existing assistive devices, but it also enables them to design and test new and unique assistive devices that would otherwise be too time or material intensive to produce.

Opensource projects like OpenCast could streamline the creation of assistive devices for patients with broken limbs, as simply uploading a scan of a patient's arm could automatically generate an effective splint or cast (William, 2018). While 3D printing itself is not particularly fast (a single cast could take upwards of 3 hours to print) using a 3D printer to automatically build assistive devices frees up occupational therapists to see and treat more patients. In an educational context, students could learn how to tweak a baseline model to fit the needs of a patient's specific injury. Furthermore, a repository of assistive devices could be made available to students to study from, similar to using of anatomical models for anatomy students.

The immediate impact of 3D printing sees students of anatomy and occupational therapy granted greater access to educational tools and equipment at a fraction of the traditional cost, creating a cheap and renewable way to "bridge the gap" between textbook study and clinical practice on patients. While dentistry finds little application for FDM 3D printing due to accuracy limitations, utilization of non-dentistry grade resin printers could provide students with an outlet to learn new dental scanning and CAD software.

5.4. Future Recommendations

Overall, a consistent and renewable supply of filament for the Forge 3D lab could increase the availability of educational tools and thus the quality of education for UNAM students. The team has identified a few potential avenues that UNAM could explore to maximize educational opportunities and capabilities yielded by the lab.

5.4.1. Curriculum Development and 3D Printer Training

Despite the presence of the Forge 3D Lab at the UNAM medical school campus, very few faculty and staff members know how to properly use and maintain the equipment. While the team was working at UNAM, only a single dedicated technician operated the lab alongside the faculty members responsible for obtaining the Dirisana+ grant. Even a sufficient supply of filament, the lab is underutilized since so few people can design, prepare, and print 3D models.

A potential solution to this problem is to introduce UNAM students to CAD and 3D printing by offering a course on the subject. The team's results found many applications of 3D printing within occupational therapy education and practice. Assistive devices such as splints, plate guards, and universal cuffs (devices that help patients hold utensils and other implements) are 3D printable, significantly reducing the time required to make the device and the cost of the device itself. Thus, offering a course on design and 3D printing would both increase the utilization of the Forge 3D Lab and teach occupational therapy students design skills that can be used in clinical practice.

However, a course on 3D design and 3D printing requires trained personnel and the computer aided design software itself. The team could not identify an obvious solution to finding trained educators, but UNAM's proximity to the Namibian Institute of Technology and the Namibian University of Science and Technology may help identify candidates. The team recommended some potential software packages that meet UNAM's requirements. Since the computer facilities at UNAM are not powerful enough to run CAD programs such as SolidWorks, two other programs were recommended: Fusion360 and Onshape.

Both Fusion360 and Onshape have educational licenses, meaning their full features are free to students at a registered university. This meant UNAM would need to obtain an educational license, but both platforms are also free with slightly limited functionality for hobbyist and non-commercial use. While both platforms work, the team recommends Onshape over Fusion360 since Onshape is a browser-based CAD platform, meaning its performance is internet dependent rather than hardware dependent, which better suits the hardware at UNAM.

While developing a course on design and 3D printing would be a large undertaking for UNAM, it would be immensely beneficial to occupational therapy students at UNAM, and it would help use the Forge 3D Lab to its full potential.

5.4.2. Mold Development for Anatomy and Dentistry

In the team's findings, many of the interviewed participants were loaned an entire human skeleton during their anatomy education. Since UNAM cannot provide students with this option, the team and participants considered 3D printing skeletons for students.

However, while 3D printing significantly lowers the cost of producing unique and complex designs, it is a relatively slow process, making mass production difficult. For example, some of the parts printed by the team took upwards of 12 hours to print. For the anatomy department, which needed multiple sets of whole skeletons, printing all the parts in a timely manner is unrealistic; this also ignored the post-processing required after printing. Large bones, such as femurs, were also too large to be printed.

Furthermore, the dentistry department relied on single-use plastic simulation teeth imported from Germany on which students practice dental procedures. However, the import cost of these teeth quickly became prohibitively expensive for the dentistry department. Specifically, each tooth costs $100 NAD; with 32 teeth per practice round and 25 students, that amounts to $80,000 NAD (approximately $4000 USD) per practice training. Hoping to reduce costs, the team considered 3D printing practice materials to reduce the cost of teaching materials. The issue is the practice teeth needed to closely mimic the properties of human teeth, which is not feasible with the 3D printers at UNAM.

Therefore, the team suggested 3D printing molds for casting skeletal parts. Instead of printing individual parts, a negative (an imprint) could be printed and processed. A casting substance such as plaster or resin would fill the negative and yield a completed part. For the anatomy department, these molds significantly reduce manufacturing time without increasing the cost of production; multipart molds also allow larger bones that otherwise are unprintable.

For the dentistry department, these molds allow for mass production of mimic teeth and enable the casting of specialized industrial resins that mimic human teeth. During the interview with Participant 2, the participant mentioned that PEEK, a specialized plastic, resembles human teeth during practice dental procedures. The team conducted research into various casting resins with similar properties to PEEK, and consequently human teeth, and discovered a casting resin manufactured by SmoothOn which matched the material requirements with a cost of $200 USD per liter. Upon discussion with Participant 2, they agreed it may be a suitable replacement for the imported German teeth, potentially saving thousands of dollars.

Thus, the team advised that the two departments investigate producing molds for mass producing teaching materials. Furthermore, the team advised the dentistry department to explore other potential resins that may have material properties that mimic human teeth for dentistry training.

5.4.3. 3D Printing Service and Monetization

The funding issues at UNAM severely limited the faculty and staff's ability to purchase even the bare essentials. During several of the team's interviews, the participants mentioned the possibility of generating an income to supplement their allotted budget using the capabilities of the Forge 3D Lab as a paid service. Additionally, as previously discussed, very few people at UNAM had been exposed to 3D printing. Thus, there was an opportunity to use the Forge 3D Lab as a 3D printing service.

Implementing this service would not be difficult for the Forge 3D Lab, especially since a similar system is already in place at Worcester Polytechnic Institute in the Makerspace. WPI students can take a training course on 3D printing which allows them to use the 3D printers for projects and classes. Once approved, students can upload their models to a web portal, and staff then prepare and print the files; the student pays for the cost of consumable materials. For UNAM, implementing a similar service would both increase awareness about 3D printing and generate a source of income for the Forge 3D Lab and the medical school.

Furthermore, the upfront cost of implementing this service is very low. The only hardware required is a Raspberry Pi to host the cloud service, which is readily available. As for the cloud service, two popular services, 3D PrinterOS, the program WPI uses in the Makerspace, and Astroprint, an alternative with similar functionality as 3D PrinterOS, have educational licensing programs. There are also additional programs which may better fit the needs of the Forge 3D Lab (Bruno et al., 2018). Thus, UNAM could set up the service with very little cost.

6. Conclusions

The exploration of the possibility of implementing 3D printing technology into the medical education field at the University of Namibia paired with the creation of a renewable filament machine, a solid foundation has been laid. Through the conduction of interviews with UNAM staff and a focus group with current students, many insights about the viability of implementing this technology were gained. Using the ideas compiled through these conversations, recommendations were developed with the goal of a better more in-depth education for medical students. The 3D printer filament machine designed and left in the Forge 3D Lab at the university will allow these recommendations to be materialized in the form of educational models that students can take home to study. By utilizing available plastic water bottles, the lab can procure 3D printer filament without worrying about the school's funding constraints. This machine will also open the door to new possible revenue sources in the form of a 3D printing queue for students and staff.

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Appendix A: In-Depth Interview Topic Guides

Appendix A.1: Topic Guide for Anatomy Department Interviews

T1: Professional Background and Area of Expertise.

- What qualifications does the subject have?
- How long has the subject been working at UNAM?
- What classes does the subject teach and what is the topic of their most recent research.

T2: Experience Learning and Teaching Anatomy

- Why did the subject choose to learn anatomy? What was their motivation?
- What was the subject's experience learning anatomy in university? Where did they go to university?
- How does the subject's education differ from the education they are offering as a professor at UNAM? Are there any practices or exercises that have changed since they completed their degree?
- Are there differences in the resources available at UNAM compared to the resources available at the subject's university of study?

T3: Areas of Improvement for Anatomy Education

- What are the benefits of studying anatomy via dissection of cadavers vs the benefits of studying models. How do 3D printed models compare with professionally made models?
- How would increased access to anatomical models change the way the subject presents anatomy education?
- Are there any specific models that the subject would like to have more of?
- What are the ethical considerations of dissecting cadavers and creating models based on said cadavers?

T4: 3D Printing in Anatomy Education

- Considering the newly formed FORG3D lab, does the subject see themselves using the resources in the lab for your work? Why or why not?

Appendix A.2: Topic Guide for Dentistry Department Interviews

T1: Professional Background and Area of Expertise.

- What qualifications does the subject have?
- How long has the subject been working at UNAM?
- What classes does the subject teach and what is the topic of their most recent

T2: Experience Learning and Teaching Dentistry

research.

- Why did the subject choose to learn dentistry? What was their motivation?
- What was the subject's experience learning dentistry in university? Where did they go to university?
- How does the subject's education differ from the education they are offering as a professor at UNAM? Are there any practices or exercises that have changed since they completed their degree?
- Are there differences in the resources available at UNAM compared to the resources available at the subject's university of study?

T3: Areas of Improvement for Dental Education

- How is the role of a Typodont different compared to anatomical models in dental education?
- How would an increased number of anatomical models effect the way that dentistry is taught at UNAM?

T4: 3D Printing in Dental Education

- Does the subject ever create their own models for demonstration in class? If so, what models?
- Considering the new resin printers recently purchased by the dentistry department, does the subject see themselves taking advantage of these printers for class demonstrations or research?
- Considering the newly formed FORG3D lab, does the subject see themselves using the resources in the lab for your work? Why or why not?
- If the subject could 3D print any teaching aid, what would it be? Tools, models, etc.?

Appendix A.3: Topic Guide for Occupational Therapy Department Interviews

T1: Professional Background and Area of Expertise.

- What qualifications does the subject have?
- How long has the subject been working at UNAM?
- What classes does the subject teach and what is the topic of their most recent research.

T2: Experience Learning and Teaching OT

- Why did the subject choose to learn OT? What was their motivation?
- What was the subject's experience learning OT in university? Where did they go to university?
- How does the subject's education differ from the education they are offering as a professor at UNAM? Are there any practices or exercises that have changed since they completed their degree?
- Are there differences in the resources available at UNAM compared to the resources available at the subject's university of study?

T3: Areas of Improvement for OT Education

- How does the use of anatomical models differ in OT education compared to fields like anatomy?
- When studying specific case studies, do students have access to a physical model of the assisted device being used in that case?
- Do OT students typically design/build their own models of assistive devices? What does that process look like?

T4: 3D Printing in OT Education

- Are there any examples of 3D printing in occupational therapy that you would like to explore with your students? Are there any specific papers or examples that you can cite?
- Would access to 3D printing, both in terms of software and materials, effect the way the subject teaches their students.

Appendix B: Bill of Materials

BILL OF MATERIALS							
PART NAME	FILE NAME	UNIT PRICE [USD]	QTY	SUB TOTAL	SUPPLIER	PURCHASED?	LINK
4in x 0.5in PIPE NIPPLE	UNAM-COTS-004 (4in x 0.5in PIPE NIPPLE)	$ 0.54	1	$ 0.54	Sinclair Services cc	YES	LINK
NOZZLE	UNAM-COTS-013 (NOZZLE)	$ 1.51	4	$ 6.04	Sinclair Services cc	YES	LINK
6in x 0.5in PIPE NIPPLE	NA	$ 0.54	1	$ 0.54	Sinclair Services cc	YES	LINK
Teflon Tape	NA	$ 0.15	1	$ 0.15	Sinclair Services cc	YES	LINK
0.5in PIPE FLANGE	UNAM-COTS-012 (0.5in PIPE FLANGE)	$ 3.02	1	$ 3.02	Sinclair Services cc	YES	LINK
M10 THREADED ROD	UNAM-COTS-017 (THREADED ROD)	$ 1.41	1	$ 1.41	Sinclair Services cc	YES	LINK
M10 NUT	UNAM-COTS-016 (FILAMENT WINDER NUT)	$ 0.14	10	$ 1.40	MEGABUILD	YES	LINK
16mm AUGER	UNAM-COTS-007 (16mm AUGER)	$ 7.46	1	$ 7.46	MEGABUILD	YES	LINK
M5 NUT	UNAM-COTS-020 (M5 NUT)	$ 0.05	10	$ 0.50	MEGABUILD	YES	LINK
M5 WASHER	UNAM-COTS-021 (M5 WASHER)	$ 0.02	25	$ 0.55	MEGABUILD	YES	LINK
WOOD SCREW 30mm	UNAM-COTS-022 (M5 WOOD SCREW)	$ 0.04	25	$ 0.88	MEGABUILD	YES	LINK
WOOD SCREW 13mm	UNAM-COTS-022 (M5 WOOD SCREW)	$ 0.02	25	$ 0.50	MEGABUILD	YES	LINK
BLADES	NA	$ 0.17	10	$ 1.70	MEGABUILD	YES	LINK
3.2mm Drill	NA	$ 3.40	1	$ 3.40	MEGABUILD	YES	LINK
2.5mm Drill	NA	$ 1.43	1	$ 1.43	MEGABUILD	YES	LINK
P320 Sandpaper	NA	$ 0.42	50	$ 21.00	MEGABUILD	YES	LINK
THRUST BEARING	UNAM-COTS-018 (THRUST BEARING)	$ 3.00	4	$ 12.00	Amazon	YES	LINK
COUPLING	UNAM-009 (COUPLING)	$ 9.99	1	$ 9.99	Amazon	YES	LINK
SHAFT COLLAR	UNAM-018 (SHAFT COLLAR)	$ 3.25	4	$ 13.00	Amazon	YES	LINK
M3 Bolt Set	NA	$ 9.99	1	$ 9.99	Amazon	YES	LINK
M3 Taps	NA	$ 7.59	1	$ 7.59	Amazon	YES	LINK
Particle Board	NA	$ 25.00	1	$ 25.00	MEGABUILD	YES	LINK
M5 Bolt Set	NA	$ 9.99	1	$ 9.99	Amazon	YES	LINK
10MM BALL BEARING	UNAM-COTS-023 (10mm BALL BEARING)	$ 1.01	8	$ 8.08	Amazon	YES	LINK
4010 Fans	NA	$ 1.90	4	$ 7.60	EcoRobotics	YES	LINK
Power cord	NA	$ 11.90	1	$ 11.90	Amazon	YES	LINK
Power Socket x2	NA	$ 16.99	1	$ 16.99	Amazon	YES	LINK
Thermistor	NA	$ 1.50	5	$ 7.50	EcoRobotics	YES	LINK
Heater Elements	NA	$ 2.50	3	$ 7.50	EcoRobotics	YES	LINK
Hot End	NA	$ 11.50	1	$ 11.50	EcoRobotics	YES	LINK
SKR Pico	NA	$ 35.99	1	$ 35.99	Amazon	YES	LINK
Raspberry Pi pico	NA	$ 5.00	1	$ 5.00	EcoRobotics	YES	LINK
TB660	NA	$ 9.98	1	$ 9.98	Amazon	YES	LINK
Bosch 7/64" Drill	NA	$ 2.05	1	$ 2.05	Amazon	YES	LINK
Encoder + Button	NA	$ 11.99	1	$ 11.99	Amazon	YES	LINK
Display	NA	$ 8.00	1	$ 8.00	EcoRobotics	YES	LINK
Nema 23	NA	$ 34.00	1	$ 34.00	Amazon	YES	LINK
Mangets 5x2mm	NA	$ 9.99	1	$ 9.99	Amazon	YES	LINK
Hall Effects	NA	$ 10.99	1	$ 10.99	Amazon	YES	LINK
24V Power Supply	NA	$ 28.66	1	$ 28.66	Amazon	YES	LINK
1.75mm ABS Filament 1kg	NA	$ 16.08	1	$ 16.08	EcoRobotics	YES	LINK
Amazon Shipping	NA	$134.47	1	$ 134.47	Amazon	YES	LINK
Amazon Import Fee	NA	$56.60	1	$ 56.60	Amazon	YES	LINK
Ecobotics	NA	$0	1	$ -	EcoRobotics	YES	LINK

OVERALL COST	
Total	$ 572.95 USD

Appendix C: Authorship Tables

Introduction and Summaries		
Section	Primary Author	Secondary Author/ Editor
Abstract	Nikesh Walling	Cassidy Choquette
Executive Summary	Nikesh Walling	Jacob Saunders and Cassidy Choquette
Introduction	Cassidy Choquette	Nikesh Walling

Background		
Section	Primary Author	Secondary Author/Editor
Fundamentals of 3D Printing	Nikesh Walling	Tobias Enoch
Recycling in Namibia	Jacob Saunders	Nikesh Walling
Recycling and 3D Printing	Jacob Saunders	Tobias Enoch
Applications of 3D Printing in Medical Education	Tobias Enoch	Nikesh Walling
Benefits of 3D Printing in Medical Education	Cassidy Choquette	Tobias Enoch

Methodology		
Section	Primary Author	Secondary Author/Editor
Study Design	Tobias Enoch	Cassidy Choquette
Sampling Strategy	Nikesh Walling	Tobias Enoch
Recruitment Procedure	Cassidy Choquette	Tobias Enoch
Measures Assessed	Tobias Enoch	Tobias Enoch
Data Collection Methods	Tobias Enoch	Cassidy Choquette
Data Analysis	Cassidy Choquette	Tobias Enoch
Ethical Considerations	Jacob Saunders	Tobias Enoch
Limitations	Nikesh Walling	Jacob Saunders

Results		
Section	Primary Author	Secondary Author/Editor
Ethics and Anatomy Education at UNAM	Tobias Enoch	Cassidy Choquette
Clinical Practice, Dentistry, and the Ethics of Material Science	Tobias Enoch	Cassidy Choquette
Occupational Therapy and Ethics of Patient Individualism	Tobias Enoch	Cassidy Choquette
Funding Constraints and Public Universities in Southern Africa	Jacob Saunders	Tobias Enoch
Tools of Anatomy Education	Cassidy Choquette	Tobias Enoch
Tradition and New Advancements in Dentistry Training	Tobias Enoch	Tobias Enoch
Occupational Therapy and Construction of Assistive Devices	Cassidy Choquette	Tobias Enoch
Development of a Filament Extruder Setup	Nikesh Walling	Tobias Enoch

Discussion		
Section	Primary Author	Secondary Author/Editor
Anatomy Education, Cadavers, and Anatomical Models	Tobias Enoch	Cassidy Choquette
Occupational Therapy and Occupational Justice	Tobias Enoch	Nikesh Walling
Recycling Waste Plastic for 3D Printing	Nikesh Walling	Tobias Enoch
Limitations and Ethical Requirements	Cassidy Choquette	Tobias Enoch
Applications of 3D Printing Recycled Materials	Tobias Enoch	Cassidy Choquette
Future Recommendations	Nikesh Walling	Cassidy Choquette
Conclusions	Jacob Saunders	Nikesh Walling

Appendix D: Qualitative Interviews & Focus Group Information

Interview Participant	Date of Interview	Interview Duration	Department/Profession
Participant 1	March 19th, 2024	1 hour, 41 minutes	Anatomy Professor
Participant 2	March 27th, 2024	59 minutes	Dentistry Technician
Participant 3	March 27th, 2024	52 minutes	Occupational Therapy Professor
Participant 4	April 4th, 2024	39 minutes	Anatomy Professor
Participant 5	April 5th, 2024	33 minutes	Anatomy Technician
Participant 6	April 5th, 2024	42 minutes	Anatomy Technician
Focus Group 1	April 5th, 2024	40 minutes	Five 4th Year Occupational Therapy Students

Appendix E: Code Book

Primary Code	Secondary Codes	Quotes	Participant
Ethics in Medical Education and 3D Printing in Medical Practice	Informed Consent Moral Gray Area	"Now we come to the process of if I take a photograph of that (cadaverous material), if I do research on that (its fine, but) , if I scan it and I make a 3D print, now it moves into an area where there isn't a legal precedent that says you're allowed to do this or that."	Participant 1
	Legal Precedent Biocompatibility	"The biggest challenge is really like managing consumables and because most if not all the stuff that we use actually have a shelf life and expiry date."..."Their material gets expired and then we're bordering on ethical guidelines."	Participant 2
	Community Consensus Cadaverous Material	"We had to apply for the Human Tissue Act to include the possibility to use cadavers that are unclaimed bodies from the mortuary."..."especially our population believe that people need to be buried."	Participant 4
	Religious/Cultural Conflict Occupational Justice Sourcing	"The general principle, I think is the moment (the specimen) is identifiable then it becomes a complex ... I think ... I think everyone sort of agrees upon it. ... So if you have ... a case that got splashed in the media. This person was death with a machete to the head five times. And now you have a skull with a machete (through it). ... "Then everyone's going to know about it (who it was) .... (Then you have) 'Ohh I was in the front of the newspapers, you can't use me' and this poor sucker who didn't make the newspapers, I can use them."	Participant 1
		"And there are a lot of cultural traditions around burials that we have to take into account and I think that's why the law has not been passed. I think there was a lot of movement from us, a lot of motivations written. ... Their cultural beliefs will being affected by allowing the disection, especially of someone that's content. If you don't make your body find that your decision. ... It takes the agency away in in a way. It's yeah. "	Participant 4

	2D vs 3D "Taking it home" Multi-Modal Learning	"Of my personal feeling is that I'm a person, learn better from different resources, I like to read in the book, I like To look at some 3 dimensional images, I like to touch a 3D model, I like to see it in the (cadaver). And my experience has been that most students prefer multimodal learning. "	Participant 4
	3D Printing as a Tool Model Matching Learning vs Clinical Practice	"It doesn't look the same. The cadavers brain is brown...and in the book it's color coded and it doesn't match"	FOCUS GROUP 1
	Traditional vs State of the Art Looking Ahead	"If I scan the thing I have a 3D model that I can show the students on screen in three dimensions that bridges the textbook with paper and it's flat. No 3 dimensions to it"..."a patient is a three-dimensional object. It's not flat."	Participant 1
	Educational Scaling Awareness of 3D Printing	"I don't think the one is better than the other. I think it's useful to have all of those with other things"..."It's like the goal is to have access to 3D in any form."	Participant 1
		"We would like to get to a point where we are able to rent a skeleton switch to say 400,000 grand is a skull. It's your skull."..."You can draw on it, you can do all the muscle attachments, you can illustrate on it."	Participant 1
		"The forensic anthropology students are about 70 in a class...I've got one specimen. I've got one hour to teach 10 different things. So what they do is they have stations, so you get in that hour where you get 5 minutes on the station. If I print that, I can have one specimen for each, so they can spend an hour sitting at one station and looking at everything comparing it"	Participant 1
"Bridging the Gap"		"For me, the digital system is, it's kind of like an add-on. It has to be a supplementary and ...Yes, it's it's, it's basically supplementary to the conventional methods of doing - It's really important that they grasp the concept fundamentally from the conventional method."	Participant 2
		"In anatomy, the three-dimensional aspect is very important."	Participant 4

		"if you touch the model, you can take the things apart and you can see rather than seeing a visual image, even if it's in 3D and you can manipulate it."	Participant 4
		"We come from a very traditional teaching background. The way we were taught was very traditional using the cadaver dissection."..."Apart from the fact that most of us are not digitally literate or electronically literate, or we taught outselves whatever we know, it's difficult to have a mind switch."	Participant 4
		"Knowing our students and where they are in their life and where they are in terms of modern technology and use of cell phones, Wi-Fi, AI, we are so far behind that it's very difficult for us to adapt. "	Participant 4
		"You cannot start to think about surgery on a person if you don't dissect"	Participant 5
		"So, and then they can feel and they can see the dimensions if you use the 3D. So I'm very positive about 3D printing"	Participant 5
		"It's a good combination to use all three of them and compare that with the textbook"	Participant 5
		"Yeah, I would actually like to print a skeleton for each student, or at least half a skeleton for them to use because they only see this in the practical"	Participant 5
		"You go in the lab and they put a sticker on a specific part, either an organ or skull muscle and then they will ask you what that is. But, at home you are only studying from a textbook, not a 3D...It was limited because you can't take anything home."	FOCUS GROUP 1

Teaching Models	Lifespan Biocomparability	"It would be helpful to have more models in class so that if you're having like a group discussion for example like there are three models and then you can divide that into three groups and just make the learning more."	FOCUS GROUP 1
	Patient Individuality Cadaverous Material	"When I was at university every group of students got a bag of bones"..."That made a huge difference. Especially with the teaching of the limbs. Knowing where the muscles are attached."	Participant 4
	Educational Scaling 2D vs 3D "Taking it home"	"I don't know how much you know about Histology, but it's basically the tissue... But that's also very basic, and I want to say flat in terms of 3D printing" "So Histology, there is a three-dimensional aspect to it, which you still don't have to realize. I've not yet come across or have an idea how to apply 3D printing, or 3D physical image, or creating an image of the model from that."	Participant 1
		"Anthropology is where we really need to use it" "She studied or followed the guy there, Steve Simms...And the problem is now she needs to now teach people and so for that you need material." "So you want to show people the bone. And now try flying with human remains, which is not really easy. So the 3D printing makes that possible. So we micro CT scan a bunch of bones cases and now you can travel with it."	Participant 1
		"So for teaching and then we have valuable specimens...So you have one that's a very good textbook example, but now you give it to students, and then a year from now, The thing is, is useless."	Participant 1
		"A lot of what we're looking at is not as much fully 3D printing models, but more about 3D printing molds to cast something out of something. That's a lot more applicable."	Participant 2
		"From a osteological perspective and the studying of limbs that made a huge difference for me."..."I think there are other things that I probably would not say is that useful to take home."..."for example, we had the students doing the heart today in dissection. So we have a lot of dissected hearts available."..."Looking at the 3D models and looking at the physical heart dissection itself, even. Almost as far apart from a flat image to the 3D model because it doesn't, I mean it's not in color. The heart looks like it's one color. There's no, the arteries are not red. The veins are not blue."	Participant 4

		"And it makes a difference to them if they can physically touch everything that they have to them. And they can put even if it's just a piece of fruit or a piece of wool, and try to mimic where the muscle is starting and where it's going to. It really helps you with learning if you actually have that available and if you can take it out, by all means you have much more time to spend with that instead of just having two hours in a practical session and week. "	Participant 4
		"At this stage, I think we can use the 3D printing if if we have to wait specimen and I think that is going to stop in a while, we are not going to get more cadavers from South Africa. We are not going to get if the law is maybe changed here and you can get it here. I don't foresee that in the next 10 years"	Participant 5
		"A 3D dissection table I would like to put in here one year in this corner for them to use because they can't go every day to the dissection because there are other year groups. If can practice in here and use this area with the 3D models it will be great"	Participant 5
		"What we also thought about is is not actually to to print the skeletons, but to print the mold. And then you can duplicate it, but say for example you are going to print 20 humans it takes a while"	Participant 5
		"The 3D printing technology, it's really, to me as an individual it's a really advanced technology. In terms of like, let me say in the school of medicine. It can address the salvage of salvage of teaching model that dentistry can use, OT can use, and the school of medicine students that they can use"	Participant 6
Cost	Public Institutions Government Funding Specimen Preparation Model Lifespan Independent Revenue Stream Awareness of 3D Printing	"Alison surface scanned our Dean." ... "So he has a board meeting every year, and right. That was just before the board meeting. We want to give him this figurine at the board meeting as well." ... "But he got suspicious. And saying 'what's this'? But then he got it and .. " 'said'... 'The big boss of the university. I'm going to tell him now. Just come and see what my people are doing.' "	Participant 1
		"So, with state hospitals, there's a the budget is, you know, quite tight in terms of buying materials to make stuff. "..."I think the prices of thermoplastic material is quite high and and the time it takes time is money in terms of private"	Participant 3
		"But the the big problem here is they want us to do something [with the 3D printers], but don't pay for that. That's the big problem. So we can actually do a lot of things, but we're strangled."	Participant 5

Patient Individuality	Time Cost Remote Living Areas Efficiency Accuracy	"Wow. That's exciting. Yeah. Then we would be so, so interested. So what I think is why I think it would be helpful is for two reasons. If it's moldable, then we can have a basic form. And once we have the patient then formed or molded more to the tailor."	Participant 3
	Assitive Devices Temporary Devices	"It can take up to two to three hours to make one splint"	Participant 3
	Looking Ahead	"So, with the 3D printer we would be able to get almost the basis - the generalized form. And then we adjust that thing to personalize it." ... "The basic structure would already save time and be very helpful for the patient."	Participant 3
		"If I think about Katsura Hospital, I don't know if you guys have seen the hospitals, but a katutura hospital, they've got one permanent occupational therapy for the whole hospital and the whole hospital is about 800 beds."..."So she needs to take two or three hours to make one splint."..."We should be seeing so many other patients".	Participant 3
		"You still need to go through the same thinking to build the 3D model, whether you use waste or you use the 3D printer. So I think I would still encourage it, but I think with a 3D printer it will more align with the principles that I was speaking about in terms of assisted device and universal design."	Participant 3
		"I don't know if I can actually give you an answer in terms of what a custom made would like because it does depend from patient to patient. It does depend on the persons context. It does depend on the culture. It does depend on what would be acceptable to them."	Patient 3
		"When we think about custom making which we in OT we do because we consider every patient as unique and we consider the context we use still use the same principles of universal design and assistive devices."	Patient 3
		"Just in terms of the environment, one of the approaches like we said compensatory, but it's also adaptation. So how do we adapt the environment in to make sure this person. And still have a quality of life."	Participant 3