Designing a Three Dimensional (3D) Flow Model of the Liver for Arterial Embolization Testing
(Technical Project)

Investigating the Underlying Reasons for Medical Schools' Increasing Adoption of 3D Models for Medical Education over Traditional Methods
(STS Project)

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction:

Medical practices have undergone a rapid evolution over the past few decades due to technological developments and changing patient needs. Traditional medical practice has revolved around whether or not a procedure can be accomplished, but modern medical thinking has shifted to focus on efficiency (Thimbleby, 2013). Because standard medical practice has advanced, modern healthcare now demands a working knowledge in sophisticated technology and techniques. The constant progression of technology in the medical field has led educators to seek equally advanced teaching methods to better prepare students for the complexities of modern healthcare systems (Dacre & Fox, 2000).

Historically, medical students have relied on methods like dissections, cadaveric studies, and textbooks for basic learning, but these conventional teaching methods struggle to address the medical field's evolving needs. Lectures and textbook learning, while foundational, have limitations in providing students with an interactive and dynamic learning experience necessary to thrive in today's healthcare environment (Densen, 2011). According to researchers, solely using these conventional methods for medical education risks producing graduates who may be proficient in traditional practice but ill-prepared for the unpredictable growth of modern medicine (Buja, 2019).

In a recent effort to close the gap between education and current practice, most medical schools have adopted the use of 3D modeling in their curriculum. This provides an additional mode of interactive learning. Despite this effort, studies conducted regarding the efficacy of 3D models in medical education have not shown evidence of statistically significant improvements in learning compared to conventional methods (Ardila et al., 2023).

3D models are not just used for students, and are often used in preoperative planning. They are especially helpful if a patient's traditional anatomy is compromised, like the presence of a tumor (Segaran et al., 2021). Hepatic tumors, which are cancerous growths on or in the liver, can grow large enough to cause severe health problems and decrease quality of life. Liver cancer is a leading cause of cancer deaths worldwide, accounting for more than 700,000 deaths each year ("Key Statistics About Liver Cancer", 2023). If the cancer is local to the liver, surgical procedures are often a treatment option ("Treatment of Liver Cancer", 2021). A 3D model of a patient's liver anatomy is highly useful for surgeons (specifically interventional radiologists) in visualizing potential problem areas, preoperative planning of surgeries, and teaching medical students. However, current physical angiography (blood vessel) models only consist of silicone approximations of arteries and only include vessels with larger diameters (Komada et al., 2022). The lack of complete anatomy in these models limits their use in a clinical and educational setting. They are only so useful in preoperative planning because they do not mimic the organ completely.

In my STS project, I will investigate the underlying reasons for the increasing adoption of 3D models in medical education over more conventional methods. In my technical project, I will design a to-scale physical 3D flow model of the liver for medical students to use for both practicing surgical techniques and preoperative planning. My technical project and sociotechnical exploration are both driven by the need to ensure that novel medical education methods equip students with skills required for modern medical practice.

Technical Project:

Embolization is a minimally-invasive procedure that is commonly used to treat hepatic (liver) tumors. It is a recently-developed therapy that works by blocking a tumor's blood supply. Because hepatic tumors thrive on highly oxygenated blood from the main hepatic artery, blocking that supply may kill it or "downstage" the tumor to a point where the patient is eligible to receive a liver transplant (Hyperarts, n.d.). At a minimum, the arterial embolization procedure is greatly effective in managing liver tumors by calming aggressive symptoms and increasing chances of long-term survival. However, it can be difficult to perform depending on the branch of the vessel (Lee et al., 2012). This is largely due to the complex hepatic tree, a large network of intertwined and interconnected blood vessels that supply the liver. In order to perform the procedure, navigating the hepatic tree is necessary to find the specific vessel feeding the tumor.

My technical capstone group and I want to create a more accurate and specific model of the liver for hepatic arterial embolization modeling by 3D printing vessels on a smaller scale than ever before. A highly accurate model will provide an environment for better preoperative planning. With the recent widespread use and advancement of 3D printers, small-scale and patient-specific liver models can now be printed based on real human computed tomography (CT) data (Witowski et al., 2019). These models can be used for preoperative planning and education in interventional radiology because it enables accurate visualization of the complex branching of blood vessels (Komada et al., 2022).

In our technical capstone, we will be extracting a hepatic vascular tree from a CT scan for printing. The CT scan, a DICOM file, will be uploaded into the rendering software 3D Slicer. To manipulate the hepatic tree into a printable and buildable model, we will create thresholds in computer assisted design (CAD) software (Fusion 360 and Rhino Medical). We will then print the model with a Formlabs resin printer. To image the printed model for testing, we will simulate blood flow with blood analogues while simultaneously imaging the model using contrast radiography techniques (x-ray and the administration of a special dye) to calculate absorption differences. The model should mimic a realistic volumetric flow rate (which is 800-1200 mL/min) of blood when pumped with blood analogues (Eipel et al., 2010).

This builds off of existing techniques that involve rendering of a CT data to print a 3D model, however it has only been done before on a ~10 mm scale. The new printers have been proven to accommodate a ~2 mm diameter in previous students' projects. However, this scale is challenging because it requires precise rendering from CT scans, which is technically demanding. Our technical question is, how well can resin 3D printing capture the minute details of the hepatic vascular system?

The deliverable of this project is a patient-specific 3D printed model of the complete hepatic tree and liver, created with high precision using medical image processing software. The model will serve as a valuable educational tool for medical professionals, allowing them to practice hepatic arterial embolization in a lifelike and accurate representation. Moreover, this model has the potential to be used for preoperative planning, increasing the likelihood of successful liver tumor treatment. The consequences of failing to address challenges with existing models are not only related to patient well-being but also have financial implications. Inefficient procedures can lead to increased healthcare costs due to additional surgeries and the need for transplantation, which is a more resource-intensive option (Bilbao, 2006). If medical students and professionals face hurdles in training for these procedures without accurate models, it could impact the quality of healthcare delivery.

STS Project:

Traditional medical education methods, like lectures and textbooks methods, have strong educational foundations and are widely accessible, but they lack the interactivity and customization that is required for modern healthcare needs. Recent technological innovation has led to the development of novel methods such as 3D printed and computerized 3D models to provide enhanced visualization and enable personalized clinical simulations; however, this is expensive and requires technical proficiency of doctors (Ardila et al., 2023). Although they are costly and many current doctors lack expertise in these technologies, medical schools continue to adopt 3D models in place of other interactive methods like dissections or cadaveric studies (Radzi et al., 2022).

In my project, I will employ the Technology Acceptance Model (TAM), which is a framework that is widely used to predict how users adopt and use new technologies. The Technology Acceptance Model "proposes that system use is a response that can be explained by user motivation, which, in turn, is directly influenced by an external stimulus consisting of the actual system's features and capabilities" (Chuttur, 2009). In the scope of my project, I propose that the "users" in this framework are educators and students, while the technological "system" is novel 3D modeling methods used in the classroom. The application of the TAM implies that the transition to 3D models in medical education is not entirely scientific, but also user motivated.

Medical education methods should consistently prioritize interactive learning approaches. The chair of medical education at the TCU School of Medicine stated, "a lot of physicians were trained in a model where they sat in classrooms from 8 a.m. to 5 p.m. … but there is a more efficient way to learn … you have to be able to practice a skill to get better" (Collier, 2019). Medical educators recognize the importance of practicing skills to produce better doctors. The interactive models used in education must be able to ensure students gain skills which mimic real-life scenarios as closely as possible. He also stated that “so much of what we do in medicine, [is] not just about the knowing, it’s about applying the skill” (Collier, 2019). The way physicians are taught has a direct impact on how physicians perform in real-life medical scenarios. It is clear that an interactive model is necessary in medical education. Understanding why medical schools are transitioning to novel technology-driven approaches to interactive models is key, because the adoption of modern methods will have a direct impact on how well doctors adapt to the changing field of modern medicine.

While advantages of new interactive models exist, there are cost and resource challenges associated with their implementation. 3D models, including the installation of 3D printers and their materials, are more expensive and resource-intensive than traditional dissection tools. Despite these hurdles, educational institutions are increasingly pushing for this shift (Brumpt et al., 2023). Understanding why schools are investing in a more costly method for hands-on learning is essential to understand factors that outweigh the economic constraints. These factors will help identify driving forces that can shift the medical education field. According to the TAM framework, the motivation behind this shift may be the users (students and educators), as it evidently is not more cost-efficient.

Furthermore, despite the promises that novel education approaches provide, there haven’t been statistically significant differences in learning outcomes between 3D models and conventional interactive methods like dissections. “A number of studies … showed that there was no difference when 3D outcomes were compared to 2D or traditional teaching.” (Azer & Azer, 2016). It is important to question why medical schools have been persistent in implementing these practices despite these minimal returns. Understanding the motivations and benefits from a user perspective (as the TAM framework suggests) may uncover the true impact of 3D modeling on the quality of medical education.

To further investigate the adoption of 3D models into medical education systems despite these drawbacks, I will utilize the Social Construction of Technology (SCOT) framework. SCOT emphasizes that technology does not inherently shape human behavior, but rather is determined by social processes and human choices (Pinch & Bijker, 1984). This approach, in conjunction with applying the TAM framework, will provide insight into how the relevant social groups or "users" (educators, students, and technology providers) have facilitated this transition.

Research Question and Methods:

My proposed research question is: Why are medical schools increasingly adopting 3D models for medical education over more conventional methods? Understanding the motivations behind this shift can help equip educational institutions and policymakers with valuable information to make informed decisions about resource allocation and more effective strategies in medical education. To answer this question, I will conduct a literature review, discourse analysis, and utilize case studies. Because this transition is recent and has occurred in the past few decades, I will focus on articles written after 2000. I will focus specifically on reviews of studies related to the effectiveness of these novel models, both for educators and students, to determine their role in shaping the adoption of novel models. Furthermore, I will also gather information about resource challenges that might be influencing this transition using keywords in a literature search on PubMed. Additionally, I will conduct a discourse analysis to examine texts produced by various stakeholders (relevant social groups from SCOT) in medical education, such as educators, students, technology providers, and policymakers. I will gather these texts from company and institutional websites (such as marketing approaches), policy documents, and educational journals (from the Department of Education). Lastly, I will analyze the effect of 3D modeling approaches in schools that have developed 3D modeling-focused programs. This gathered information will allow me to draw conclusions about the adoption of 3D models in medical education and its true underlying motivations.

Conclusion:

My technical project aims to create a precise, patient-specific 3D printed model of the hepatic vascular tree, enhancing medical training and the quality of liver tumor treatments. My STS project delves into the motivations driving the shift from conventional methods to 3D models in medical education, empowering institutions and policymakers with insights for informed decisions about resource allocation and educational strategies. By advancing the state-of-the-art for liver modeling while investigating changing educational practices, I hope to not only engineer a groundbreaking device, but to understand its place in the educational community.

References

Ardila, C. M., González-Arroyave, D., & Zuluaga-Gómez, M. (2023). Efficacy of three-dimensional models for medical education: A systematic scoping review of randomized clinical trials. *Heliyon*, *9*(2), e13395. https://doi.org/10.1016/j.heliyon.2023.e13395

Azer, S. A., & Azer, S. (2016). 3D Anatomy Models and Impact on Learning: A Review of the Quality of the Literature. *Health Professions Education*, *2*(2), 80–98. https://doi.org/10.1016/j.hpe.2016.05.002

Bilbao, J. I., Martínez-Cuesta, A., Urtasun, F., & Cosín, O. (2006). Complications of Embolization. *Seminars in Interventional Radiology*, *23*(02), 126–142. https://doi.org/10.1055/s-2006-941443

Brumpt, E., Bertin, E., Tatu, L., & Louvrier, A. (2023). 3D printing as a pedagogical tool for teaching normal human anatomy: A systematic review. *BMC Medical Education*, *23*(1), 783. https://doi.org/10.1186/s12909-023-04744-w

Buja, L. M. (2019). Medical education today: All that glitters is not gold. *BMC Medical Education*, *19*(1), 110. https://doi.org/10.1186/s12909-019-1535-9

Chuttur, M. (2009). Overview of the Technology Acceptance Model: Origins, Developments and Future Directions. *All Sprouts Content*, *9*(37). https://aisel.aisnet.org/sprouts_all/290

Collier, C. (2019, February 12). *Hands-On Learning Helps Medical Students Put Patients First*. TCU Magazine. https://magazine.tcu.edu/winter-2019/hands-on-learning-helps-medical-students-put-patients-first/

Dacre, J. E., & Fox, R. A. (2000). How should we be teaching our undergraduates? *Annals of* *the Rheumatic Diseases*, *59*(9), 662–667. https://doi.org/10.1136/ard.59.9.662

Densen, P. (2011). Challenges and Opportunities Facing Medical Education. *Transactions of the American Clinical and Climatological Association*, *122*, 48.

Eipel, C., Abshagen, K., & Vollmar, B. (2010). Regulation of hepatic blood flow: The hepatic arterial buffer response revisited. *World Journal of Gastroenterology*, *16*(48), 6046–6057. https://doi.org/10.3748/wjg.v16.i48.6046

Hyperarts, R. M. (n.d.). *General Surgery—Hepatic Artery Embolization*. Retrieved October 24, 2023, from https://generalsurgery.ucsf.edu/conditions--procedures/hepatic-artery-embolization.aspx

Key Statistics About Liver Cancer. (n.d.). Retrieved October 24, 2023, from https://www.cancer.org/cancer/types/liver-cancer/about/what-is-key-statistics.html

Komada, T., Kamomae, T., Matsushima, M., Hyodo, R., & Naganawa, S. (2022). Embolization using patient-specific vascular models created by a 3D printer for difficult cases: A report of two cases [Nagoya University Graduate School of Medicine, School of Medicine]. In *Nagoya Journal of Medical Science* (Vol. 84, Issue 2, pp. 477–483). https://nagoya.repo.nii.ac.jp/records/2002895

Lee, E., Leon Pachter, H., & Sarpel, U. (2012). Hepatic Arterial Embolization for the Treatment of Metastatic Neuroendocrine Tumors. *International Journal of Hepatology*, *2012*, e471203. https://doi.org/10.1155/2012/471203

Pinch, T. J., & Bijker, W. E. (1984). The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other. *Social Studies of Science, 14*(3), 399–441. https://doi.org/10.1177/030631284014003004

Radzi, S., Chandrasekaran, R., Peh, Z. K., Rajalingam, P., Yeong, W. Y., & Mogali, S. R. (2022).

Students' learning experiences of three-dimensional printed models and plastinated specimens: A qualitative analysis. *BMC Medical Education, 22*, 695. https://doi.org/10.1186/s12909-022-03756-2

Segaran, N., Saini, G., Mayer, J. L., Naidu, S., Patel, I., Alzubaidi, S., & Oklu, R. (2021). Application of 3D Printing in Preoperative Planning. *Journal of Clinical Medicine, 10*(5), 917. https://doi.org/10.3390/jcm10050917

Thimbleby, H. (2013). Technology and the Future of Healthcare. *Journal of Public Health Research*, *2*(3), e28. https://doi.org/10.4081/jphr.2013.e28

Treatment of Liver Cancer, by Stage. (n.d.). Retrieved October 24, 2023, from https://www.cancer.org/cancer/types/liver-cancer/treating/by-stage.html

Witowski, J., Wake, N., Grochowska, A., Sun, Z., Budzyński, A., Major, P., Popiela, T. J., & Pędziwiatr, M. (2019). Investigating accuracy of 3D printed liver models with computed tomography. *Quantitative Imaging in Medicine and Surgery*, *9*(1), 432–452. https://doi.org/10.21037/qims.2018.09.16