

## ANATOMY IN ACTION: INCORPORATING 3D PRINTING IN PRE-COLLEGIATE ANATOMY EDUCATION

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Increasing and maintaining student engagement within anatomy education at a pre-collegiate level is a challenge that educators continue to encounter. Finding an appropriate level of difficulty that prepares students for the rigor of undergraduate anatomy education while balancing the need to inspire student interest in STEM-related fields of study can inadvertently discourage students, particularly when content is relayed in a 'traditional' lecture-based curriculum.

The University of Colorado's Pre-Health Scholars Program (CUPS) is an academic enrichment program for high school students from under-represented minority groups who are interested in healthcare and STEM-related professions. To address the challenges in pre-collegiate anatomy education, the CUPS anatomy curriculum has shifted away from instruction that is purely lecture-based, to a project-oriented curriculum utilizing 3D printing. Here, students are encouraged to connect hands-on experiences and collaborate on individualized projects that require mastery of anatomical principles to create. Students are also introduced to anatomic structures in a multi-dimensional fashion that allows them to examine the complementary relationship between structure and function. This model of curriculum has the potential to improve engagement and create better foundations of anatomical knowledge through thoughtful instructional design. This article focuses on the design decisions and curricular components of this course.

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### INTRODUCTION

The CU Pre-Health Scholars Program (CUPS) is committed to providing educational enrichment for underserved high school students who are interested in healthcare and STEM-related professions in the metropolitan area surrounding Aurora, CO. Because anatomy is regarded as a cornerstone of many health professions, and is also a facet of numerous pre-health programs, the CUPS Program regards innovative approaches to anatomy education as a vital component to an optimally beneficial curriculum for students.

### Holistic Pre-Collegiate Anatomy Education

Traditionally, education programs that support high school students who seek to become the first in their families to attend a college or university focus on supplementing perceived gaps in students' academic and social capital (Yosso, 2005, p. 70). As a result, mentorship and workshops tend to focus on college preparation, scholarship application processes (e.g., financial aid, SAT preparation), executive functioning skills, and supplemental math and English instruction as their primary objectives. The CUPS program fit into this model during the first fifteen years of its operation while providing courses that met the unique needs and interests of students who plan to enter health professions.

The CUPS Program's vision has since moved away from such deficit models of education and now incorporates a holistic perspective of student personal experiences and interests, while also promoting an understanding of social determinants of health. Within the redesigned curricula, these values are applied using cutting-edge medical education

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practices alongside more traditional pre-collegiate academic preparation. To achieve this vision, CUPS Scholars participate in longitudinal courses that build upon their knowledge and cultural values to enhance their critical thinking, collaboration, communication skills, and self-advocacy skills. Through these longitudinal courses, CUPS Scholars deepen their understanding of social systems and social determinants of health alongside more traditional instruction in math, science, literacy, financial aid, and the college application process. Students also participate in sessions that aim to expose them to various careers in healthcare and STEM-related fields throughout the academic year. During the summer, students participate in a robust anatomy curriculum that builds upon the principles introduced during the academic year. This longitudinal and holistic approach empowers students to infuse empathy, critical thinking, and social change while exploring their personal and professional paths.

The CUPS Program sought to expand this holistic vision of collegiate preparation into its biomedical coursework, which led to the creation of the *Anatomy in Action* curriculum. This curriculum encourages self-advocacy and collaboration skills through a project-based approach to anatomy education. While students continue to receive anatomy education through lecture-based and hands-on instruction, they also have the freedom to choose their project topics based on their own interests. Special attention was paid to the integration of several modalities of exploring anatomic principles that would augment their engagement in addition to their understanding. This serves to promote anatomy as more than an important subject matter in the health professions, but also as a personal experience that can align with social beliefs and goals (Williams & Bendelow, 1998).

## THE LAST TRADITIONAL CUPS CURRICULUM

The summer of 2018 marked the last traditional anatomy course for CUPS. This course remained innovative in the variety of methods used to introduce students to anatomy, with the goal of engaging students in unique ways. Computer-based learning, organ dissection, and full cadaver prosection viewings were used to introduce students to anatomic structures, while access to plastinations, medical imaging, lecture-based instruction, and even living anatomy activities were all utilized to emphasize functional anatomical principles. The support of the Modern Human Anatomy (MHA) program, a graduate-level anatomy program at the Anschutz Medical Campus, was instrumental in securing opportunities for students to experience anatomy in a variety of different contexts.

As Estai and Bunt (2015) highlight in their review of anatomy pedagogies, there are a wide variety of teaching modalities that can be implemented successfully in anatomy education. While their article focuses on higher education anatomy teaching, many of the teaching practices discussed were used during the summer of 2018 for CUPS students in an attempt to provide multimodal exposure that would prepare them to be successful in a college-level anatomy course.

### Rationale for a New Curriculum

Despite the interactive activities, the curriculum's assessments required a high level of rote memorization and understanding of dense anatomical concepts without providing a personal context for framing the newly acquired knowledge. Though the original six-week course incorporated a variety of instructional activities, testable material on the weekly lab

WEEK	SESSION TITLES	EXAMPLES OF SPECIFIC ACTIVITIES/CONTENT
1	Introduction to Anatomy, Nomenclature, Basic Skeletal System Epithelium & Muscle	<ul style="list-style-type: none"> <li>Skeletal system activity, including access to bones/full skeleton model</li> <li>Guided virtual histology lab for limited epithelium and the 3 muscle tissue types</li> </ul>
2	Upper & Lower limb	<ul style="list-style-type: none"> <li>Basic muscles and movements</li> <li>Cadaver lab visit</li> </ul>
3	Thorax & Abdomen	<ul style="list-style-type: none"> <li>Heart &amp; Lungs, Gastrointestinal tract</li> <li>Cadaver lab visit</li> </ul>
4	Pelvis	<ul style="list-style-type: none"> <li>Urogenital System</li> <li>Animal kidney dissection</li> </ul>
5	Nervous System - Central & Peripheral	<ul style="list-style-type: none"> <li>Brain, Nervous System Division, Basics of Cranial Nerves</li> <li>Animal brain dissection</li> </ul>
6	Medical Imaging & Clinical Anatomy	<ul style="list-style-type: none"> <li>Introduction to medical imaging modalities and how to visualize anatomy</li> </ul>

**TABLE 1.** CUPS 2018 anatomy curriculum outline.

quizzes, midterm, and the final exam were largely derived from lecture-based instruction (see Table 1).

The original design of the anatomy course presented challenges that were obvious in student-provided feedback and class performance. Many reported feeling dissuaded from pursuing a career in medicine based on their experience in the course, which went against one of the program's aims to inspire student interest in healthcare and STEM-related fields.

Though challenges are expected with the acquisition of knowledge and skills at any stage in life, inspiration at the earliest stages of this process is important and identifying personal connections to learned material can be a powerful avenue for sustained study. With this, the CUPS program sought to redesign its curriculum to not only improve student experience and engagement but to better align with its vision for holistic and personalized health education. The new curriculum shifted away from only using cadavers and dissection, and towards medical imaging and modeling. This allows for greater customization of student projects, as they are no longer restricted by the realities of learning from a single body, and each student or group can choose their own mode of learning based on their interests (Smith et al., 2017, p.45).

## REDESIGNING THE CURRICULUM

### The Design Team

The CUPS program director, a former CUPS program coordinator, and two members of the Modern Human Anatomy (MHA) Master's program co-designed the curriculum. Each member of the team brought different levels of knowledge related to anatomy and curriculum design, which influenced the role they played.

The CUPS program director, with an MEd in Social Justice Education, brought a wealth of knowledge of group dynamics and social-emotional learning. They conceptualized the new curriculum in alignment with the new CUPS vision and provided resources related to incorporating collaborative problem solving and meta-cognitive thinking.

A former CUPS program coordinator, as a University of Colorado School of Medicine student with a background in information technology and anatomy, was able to provide input on the technical execution of the 3D printing systems, as well as the overarching integration of the curriculum.

Having taught the last anatomy class, a recent MHA program graduate provided insight into the unique needs of the CUPS students. She took the lead during the academic year and mentored the second year MHA student as he developed the curriculum for the summer. During the summer, two MHA master's students joined the teaching team as teaching assistants. They became the main anatomy instructors during

the following academic year with the intention of modifying the curriculum based on the strengths and weaknesses they observed. Providing continuity between one year and the next was the intention behind this model of co-design.

### The Design Process

The process of redesigning the anatomy curriculum began with a discussion among CUPS program leadership, anatomy instructors from the MHA Program, and feedback from students in the summer of 2018 class regarding possibilities for increasing student engagement. There was a consensus reached during the discussion to focus on hands-on learning activities. Some of the options considered included clay modeling of anatomic structures, integrating the use of body paint to denote upper/lower extremity muscle anatomy, expanding the use of plastinated organs, and 3D printed modeling. Students were subsequently presented with all of these options and collectively chose to explore 3D printing, with most citing the real-world applications of 3D modeling and its connection to STEM. CUPS leadership and anatomy instructors also recognized the difficulty of accurately depicting anatomic structures using molded clay, the limited use of surface-level depictions using body paint, and the limited availability of plastinated organ specimens. 3D printed modeling was decided on as a means of tactile engagement with anatomic structures, as well as visuospatial engagement during the rendering process. The team incorporated multimodal project options to accommodate a wider variety of learning styles, and to further increase student engagement.

Students expressed the desire to work in groups to overcome the intrinsically isolating nature of rote memorization, while CUPS leadership and anatomy instructors recognized the benefit of group work when considering the limited number of instructors available to guide students and a feasible number of printing stations. Group work also had the potential benefit of giving students the opportunity to grow socially and emotionally. The design team created worksheets and discussions to teach skills related to coming to a consensus, setting realistic expectations, and delegating responsibilities within each group. With this, a project-based approach was decided upon that would integrate elements of backward design in achieving the previously established anatomy learning objectives.

### Applying Elements of Backward Design and Project-Based Learning

The design team used Backward Design and project-based learning to structure the curriculum. Wiggins and McTighe (1998) developed the Backward Design approach to curriculum design to help teachers align learning outcomes with activities, texts, and assessments. According to this approach: "One starts with the end—the desired results (goals or standards)— and then derives the curriculum from the evidence

of learning (performances) called for by the standard and the teaching needed to equip students to perform” (p. 7).

Backward Design requires teachers to develop learning goals that identify how students will demonstrate mastery of content and skill acquisition. Teachers base their assessment methods on these goals, and with these assessment methods in mind, teachers identify texts and learning experiences that will enable students to succeed. This approach enables teachers to scaffold their lessons and clearly assess student progress (Childre et al., 2009, p. 7).

The design team identified learning goals connected to social and emotional learning in addition to content and skills explicitly related to anatomy. Anatomy learning objectives included identifying anatomic landmarks, applying anatomic nomenclature, and applying concepts from the four pillars of anatomy (gross anatomy, histology, embryology, and neuroanatomy). Objectives for social and emotional learning included the ability to listen to and understand various perspectives within a group and to manage conflict collaboratively. With these objectives in mind, the design team developed formative assessments (such as quizzes and worksheets) to measure student progress and provide feedback throughout the class. For the summative assessment where students would demonstrate content mastery and skill acquisition, the team designed a final project. The application of backward design within the curriculum is exemplified by the following learning objective, activity, and assessment trio:

*Learning Objective:* “Develop communication and collaboration skills to achieve project completion.”

*Activities:* Regular meetings with mentors and activities to determine group roles based on students’ strengths.

*Assessments:* reflections on group progress and cohesion, feedback from mentors.

To achieve holistic learning objectives, the team turned to project-based learning to guide learning experiences. According to Stefanie Bell (2010), in project-based learning, “students drive their own learning through inquiry, as well as work collaboratively to research and create projects that reflect their knowledge. From gaining new, viable technology skills, to becoming proficient communicators and advanced problem solvers, students benefit from this approach to instruction” (p.39). The seven essential elements of design for project-based learning according to the Buck Institute for Education (2019) include: (a) *A Challenging Problem or Question*, (b) *Sustained Inquiry*, (c) *Authenticity*, (d) *Student Voice and Choice*, (e) *Reflection*, (f) *Critique and Revision*, and (g) *Public Product*.

This student-centered approach to learning connects directly to the CUPS mission of providing opportunities for

students to see their skills, interests, and values as relevant to their academic aspirations. The design team chose project-based learning to structure the course with this mission in mind.

As demonstrated in Table 2 (next two pages), they used the Backward Design method to translate the seven essential elements into concrete curricular components. They developed learning objectives that aligned with each of the elements, which were informed by similar courses taught within the Modern Human Anatomy masters-level program at the University of Colorado, Anschutz Medical Campus. With the learning objectives as a guide, the team created activities, assignments, and assessments that adhered to the student-centered approach.

## CONSIDERATIONS FOR A MAKERSPACE AND 3D PRINTING

### What is a Makerspace?

With the objective of inspiring students to explore scientific principles while creating personal connections to the content being taught, integrating the use of a makerspace was considered a viable means of accomplishing this. Fundamentally, a makerspace is an area where a group of people can collaborate and explore ideas through hands-on experiences (Make, 2021). This concept was inspired by the MAKE publication created in 2005, which explored the richness and potential of integrating the use of materials, tools, and electronics in creation and inquiry. This movement quickly gained momentum following the first Maker Faire in 2006 held in the San Francisco area, with other major cities soon following suit. In 2017, nearly 200 large-scale events were held with individual events boasting attendance in the hundreds of thousands (Maker Faire, n.d.). The utility of makerspaces in education now has a substantial body of data demonstrating the benefits of hands-on activities in creating an engaging learning environment (Holstermann, 2010).

### Why 3D Printing?

Inspired by a workshop on the use of 3D printing in health-care, CUPS Program leadership again sought to enlist the assistance of the Modern Human Anatomy program at the University of Colorado School of Medicine in constructing a framework for the anatomy course. The program combines anatomy education with digital imaging techniques and modeling to emphasize a multimodal approach to anatomy education. It was decided that a project-based approach would enable students to develop and apply skills used by medical practitioners and researchers while demonstrating their knowledge of anatomy in an applied and collaborative way.

3D printing was identified as a potential modality to incorporate due to its ability to combine anatomy instruction

KEY COMPONENTS OF PROJECT BASED LEARNING	EXEMPLAR OBJECTIVES	EXEMPLAR ACTIVITIES	EXEMPLAR ASSESSMENTS
Challenging Problem or Question	<ul style="list-style-type: none"> <li>Students create a final project that answers the question “how do we create an anatomic model to help the public understand a complex medical issue?”</li> </ul>	<ul style="list-style-type: none"> <li>Lectures and activities focused on foundational anatomy education concepts and topics</li> <li>Exploration of existing 3D printed anatomic models</li> <li>Discussions with mentors</li> </ul>	<ul style="list-style-type: none"> <li>Students created 3D Models and presentation posters to demonstrate the answer to the guiding question</li> </ul>
Sustained Inquiry	<ul style="list-style-type: none"> <li>Analyze peer reviewed articles relevant to their final projects</li> <li>Identify data sets of medical images to use to create their 3D models</li> </ul>	<ul style="list-style-type: none"> <li>Lessons on conducting scholarly research, identifying useful key word searches and how to cite references in APA format.</li> <li>Two class periods dedicated to supporting students find and review current literature in the area of interest related to anatomy</li> <li>Guided exploration of a medical image database</li> </ul>	<ul style="list-style-type: none"> <li>Students wrote a research paper detailing the need for their 3D model and the anatomic structures exemplified by their model.</li> </ul>
Authenticity	<ul style="list-style-type: none"> <li>Identify practical application of 3D printed anatomical models</li> <li>Develop individual research questions based on their personal or professional interests related to health care</li> </ul>	<ul style="list-style-type: none"> <li>Discussions with mentors and instructors about use of 3D modeling for surgical planning or patient education</li> <li>Individual research</li> </ul>	<ul style="list-style-type: none"> <li>Written reflection on how group projects relate to real world application of their 3D models and how anatomic concepts can be more easily communicated to others.</li> </ul>
Student Voice and Choice	<ul style="list-style-type: none"> <li>Collaborate with group members to determine final project focus and research question</li> <li>Assign group roles based on members’ strengths, areas of growth and interests</li> </ul>	<ul style="list-style-type: none"> <li>Small group discussions about group roles</li> <li>Worksheets to identify student interest</li> </ul>	<ul style="list-style-type: none"> <li>Students developed their research questions based on medical issues they found interesting and/or impacted someone they know</li> <li>Students wrote a project proposal based on the decisions made during small group discussions</li> </ul>
Reflection	<ul style="list-style-type: none"> <li>Evaluate project plan for alignment with goals and limitations of the 6-week program.</li> <li>Analyze cohesion of their group and efficiency of their collaborative process</li> </ul>	<ul style="list-style-type: none"> <li>Worksheets to guide individual reflections on personal and group progress throughout the year</li> <li>Small group discussions about skills and group roles</li> <li>Instructors provided rubrics to guide final reflection paper</li> </ul>	<ul style="list-style-type: none"> <li>Final reflection paper on their experiences learning anatomy and working on their group projects</li> </ul>

**TABLE 2.** Connections between objectives, activities, and assessments.

KEY COMPONENTS OF PROJECT BASED LEARNING	EXEMPLAR OBJECTIVES	EXEMPLAR ACTIVITIES	EXEMPLAR ASSESSMENTS
Critique and Revision	<ul style="list-style-type: none"> <li>• Articulate individual strengths and areas of growth</li> <li>• Implement feedback given by instructors and mentors</li> </ul>	<ul style="list-style-type: none"> <li>• One on one meetings with instructors to discuss strengths and areas of growth</li> <li>• Opportunities to increase grades by resubmitting assessments based on written feedback</li> <li>• Meeting with and receiving feedback with members of from a department on campus that frequently created anatomical models for surgical planning or patient education.</li> </ul>	<ul style="list-style-type: none"> <li>• Students' ability to implement feedback was determined by the quality of their final 3D model and by comparing and contrasting rough and final drafts of their research papers</li> </ul>
Public Product	<ul style="list-style-type: none"> <li>• Assess key skills related to public speaking</li> <li>• Achieve personal goals related to improving public speaking</li> <li>• Create research poster according to provided guidelines</li> </ul>	<ul style="list-style-type: none"> <li>• Mini-lecture and small group discussion about public speaking skills and developing research posters</li> <li>• Goal setting worksheet related to public speaking skills</li> <li>• Practice and receive feedback in preparation of Learning symposium</li> </ul>	<ul style="list-style-type: none"> <li>• Present research poster and final 3D model at Learning Symposium</li> </ul>

**TABLE 2 (CONT.).** Connections between objectives, activities, and assessments.

with an individualized creative process that students could tailor to their personal interests. The technology also has the potential to augment visuospatial acquisition of anatomic landmarks, scale, and basic principles of structure and function. With the use of 3D printing becoming increasingly common in surgical planning, medical trainee education, and its utility in creating a safe environment for trainees to hone their skills, this seemed like a natural fit (Ganguli, 2018).

There were other considerations that made 3D printing a potentially powerful tool in the acquisition of principles fundamental to anatomy and STEM-related applications. 3D printing allows students to appreciate scale and function in a way that traditional instruction can struggle to replicate. Digitally constructing a model allows students to manipulate and play with the dimensions and scale of the model before having the tactile experience with the printed model (Erolin, 2019).

3D printing applications extend far beyond the realm of anatomy education, as the technology also has applications in patient education, tool design, prosthetic development,

and bioprinting (printing of viable tissue structures). The CUPS Program recognizes the importance of introducing students to advanced technologies early in their education, as their use is likely to become more common in future healthcare and STEM-related professions.

### Constructing the Makerspace

Prior to the construction of the makerspace, a single Prusa printer was purchased using department funds and was used to print anatomic objects in exploring its specific use case. When it became clear that 3D modeling could be implemented on a larger scale within the CUPS program, the Office of Inclusion and Outreach at the University of Colorado was contacted to secure a larger space. The process of finding and securing a potential space took approximately three months.

An awareness of the use of creative technology in healthcare led the CUPS program director to conceptualize the Beehive (the CUPS makerspace). The development of the Anatomy in Action curriculum, however, provided the impetus to actualize that vision. The Beehive, so named to invoke an ethos of

collaboration much like a colony of bees, contains five Prusa i3 MK 3 printers, a Glowforge laser cutter, a soldering station, components for creating e-textiles, and a fabric printer. In addition to the computer-based technology, there are also three sewing machines and a scroll saw. CUPS program director focused on cost, reliability, and ease of use when determining which machines to purchase.

Without a prior background in creative technology, the CUPS program director relied heavily on the insight of the lab manager of Inworks, the makerspace at the University of Colorado, Denver. The Ultimaker S5 and Prusa i3 MK3 were the top contenders when considering potential platforms. The Ultimaker S5 is highly reliable in creating accurate prints, can print with multiple materials simultaneously, and has cloud-based software. The Prusa i3 MK 3 can be purchased as an unassembled kit or an already assembled machine at a greater cost, either option being more cost-effective than the Ultimaker platform. Believing there would be value in learning the mechanics of the 3D printer by assembling it, and with cost savings in mind, CUPS leadership decided to purchase the kits. The kit took almost 20 hours to put together, and the printer was not as reliable as it would have been had the machines been assembled by professionals. Ultimately, the CUPS program director hired undergraduate students from the bio-engineering department to service

and maintain the machines. Though the Ultimaker platform was more costly on its own, the decision to use Prusa kits proved to be more than double the cost of using the Ultimaker platform when the salary costs of personnel needed to effectively utilize the Prusa i3 MK3 platform were taken into account. Had the Ultimaker S5 been used, the upfront costs would have been higher, but minimal assistance to run and maintain the machines would have been required. To maintain uniformity in the printing platform used, and now having more detailed knowledge of the platform's mechanics, four more Prusa i3 MK3 printers were purchased and assembled (five printers total).

The Beehive is housed in a 200 square-foot office within a building designed for standard classrooms and offices at the University of Colorado, Anschutz Medical Campus. This set-up constrained both the types of materials that could be used and how many students could comfortably access the equipment at any given time. Before the CUPS program director purchased the equipment, they consulted with members of the University's offices of Environmental Health and Safety (EHS) and Risk Management. Due to a lack of proper ventilation or fume hoods, EHS only provided permission to use filaments made of PLA or PETG, as all others released chemicals that could be hazardous. Had the Beehive been in a traditional lab setting or in a room with

MONTH	TITLE	TOPICS AND/OR ACTIVITIES COVERED
September	"I Am Anatomy:"What is anatomy?	<ul style="list-style-type: none"> <li>• What is anatomy, why is it important.</li> <li>• Introduction to the 4 pillars of anatomy the research project</li> </ul>
October	Orienting Yourself in Anatomy	<ul style="list-style-type: none"> <li>• Latin and Greek roots, basic pre-fixes, directions, planes</li> <li>• Regional anatomy and orientation</li> </ul>
November	Introduction to Technology in Anatomy & 3D Modeling	<ul style="list-style-type: none"> <li>• MRI, CAT Scans, 3D Slicer, Blender</li> <li>• Machines for 3D Printing</li> </ul>
December	The 4 Pillars of Anatomy in Practice	<ul style="list-style-type: none"> <li>• Lab Visits, students explore the use of 3D printing in surgical planning, research and patient education.</li> <li>• Students submit interest forms specifying organ system, etc.</li> </ul>
January	Project Phase 1, Part 1: Research	<ul style="list-style-type: none"> <li>• Explain significance of, and procedure for conducting a literature review.</li> <li>• In groups, students practice identifying key terms and performing a literature review</li> </ul>
March	Project Phase 1, Part 2: Research & Presentation	<ul style="list-style-type: none"> <li>• Students individually present projects orally</li> <li>• Highlighting their pillar, the system or disorder, and their goals for the project</li> </ul>
April & May	Project Phase 2: Planning	<ul style="list-style-type: none"> <li>• Split into teams based on project goals (3D model, 3D print, working with histology or existing resources, etc.)</li> <li>• Students devise project timeline and goals for the summer</li> </ul>
Summer	Project Phase 3: Resource Creation & Presentation	<ul style="list-style-type: none"> <li>• Project-focused anatomy lessons and 3D printing workshops</li> <li>• Poster presentation session (the first CUPS Symposium)</li> </ul>

**TABLE 3.** Anatomy in Action year-long workshops.

access to a window, EHS would have permitted a wider variety of printing materials. The limited area meant that no more than four students could work in the room at one time.

## A NEW CURRICULUM IN THE 2018-2019 ACADEMIC YEAR

The new curriculum, now referred to as Anatomy in Action, now included a year-long series of workshops (see Table 3). The intention of expanding the curriculum from a summer to a year-long course was to give students more time to digest and apply the information. This also allowed for the integration of instruction on 3D printing and design without increasing the cognitive load students experienced. Failing to increase the length of the course would have likely had a negative impact on student engagement and the goal of inspiring students to recognize the possibilities within healthcare and STEM-related fields.

Modern Human Anatomy instructors helped develop these workshops to provide students with the foundational knowledge of anatomy, medical imaging, and research methods. They began the year with a focus on the four pillars of anatomy, (Gross Anatomy, Histology, Embryology, and Neuroanatomy). An overview of the four pillars would enable students to see how systems function and are interconnected in the broadest sense. This overview would provide background information students needed to develop a research question. By providing this foundation during the

academic year, students had time to execute their research projects during the summer. Students received the necessary instruction on anatomic orientation and a foundational framework for interpreting anatomy in medical imaging to maximize the benefit of incorporating these modalities into the curriculum. The multimodal introduction of anatomic principles through lectures, a digital platform prior to printing, physical modalities in settings like the cadaver lab, and a tactile medium when the model was finally printed aimed to reinforce anatomy content in a well-rounded approach

Keeping in line with the CUPS mission and vision, the curriculum and teaching teams provided ample opportunities for students to reflect on their knowledge and interest in anatomy, how it connects to their values and goals, and the skills they could bring to the project. Reflections took the form of class discussions, surveys, and written assignments. Students were also encouraged to make connections with content introduced throughout the longitudinal curriculum, like how their project might relate to social determinants of health and wellness.

The summer curriculum expanded on students' background knowledge of anatomy while introducing them to 3D modeling skills. During the six-week summer curriculum, students split their time between working on their group projects and participating in more traditional anatomy lectures and labs that focused on their chosen study area (see Table 4).

WEEK	DESCRIPTION
1	<ul style="list-style-type: none"> <li>• Body Structure/Organization Lecture</li> <li>• Introduction to Summer Projects and Groupwork</li> </ul>
2	<ul style="list-style-type: none"> <li>• Building and Manipulating Models Activity</li> <li>• Literature Search</li> <li>• Thorax and Cardiovascular System Lecture</li> <li>• Introduction to Medical Imaging Lecture</li> <li>• Slicer Workshop and Troubleshooting</li> <li>• Modeling Resources and Mentor Check-in</li> </ul>
3	<ul style="list-style-type: none"> <li>• Abdomen and Digestive System Lecture</li> <li>• Cadaver Lab Visit</li> <li>• 3D Printing Workshop Group Activities</li> <li>• Literature Search, Digital Modeling Group Activities</li> </ul>
4	<ul style="list-style-type: none"> <li>• Nervous System Lectures and Brain Organ Dissection</li> <li>• Modeling Resources and Mentor Check-in</li> </ul>
5	<ul style="list-style-type: none"> <li>• Pelvis and Urogenital System Lecture</li> <li>• 3D Printing Activities and Mentor Check-in</li> </ul>
6	<ul style="list-style-type: none"> <li>• 3D Printing Activities</li> <li>• Final Presentations</li> </ul>

**TABLE 4.** CUPS summer anatomy curriculum outline.



Anatomy lectures concluded with group activities and group discussions to allow students an opportunity to collaborate and learn from one another. Sessions that focused only on completing group projects reserved time for students to put acquired knowledge into practice. Exposing students to elements of a college-level anatomy class and contextualizing their projects informed the decision to maintain lecture-based aspects of the previous anatomy course while incorporating group activities following didactics was important for fostering cohesive student groups and providing structure. This multimodal approach to instruction was designed to respond to the variety of ways students relate to information. Some students learn best through reading and traditional lectures, while others acquire more information through hands-on activities (Prithishkumar & Michael, 2014, p. 184).

### Student Projects

Prior to printing their final projects, students also printed other anatomic models that provided the opportunity to experience the modeling process applied to an organ system that might not have been the focus of their chosen project. When feasible, these models could be printed in sections or slices, which allowed students an internal view of structures like the heart. Resources like Embodi3D, an online library of printable anatomic structures, were used to print a variety of anatomic models (Embodi3D, 2019).

To create their final projects, MRI and CT scans were rendered using 3D Slic3r software and printed as 3D models. This software is utilized by clinicians and medical researchers to create 3D models for surgical planning and patient education (Slic3r, 2019). Students prepared their 3D models for printing using PrusaSlic3r and printed them on Prusa i3 MK3 3D printers (see Figure 1).

In addition to 3D printing their models and composing reflections on their experiences, students created research posters as part of their final project (see Figure 2). Students presented their research findings and 3D models during an academic symposium at the end of the summer. This event was modeled after the University of Colorado Undergraduate



**FIGURE 1.** Prusa i3 MK3 3D printers in the CUPS makerspace.

Research Symposium and allowed students to experience an important element of academic research by presenting their posters and findings. Students' families, educators at the University of Colorado, and members of the community were also invited to attend the symposium.

Students provided feedback on the course through administered surveys throughout its implementation and at its completion. Students reported being more engaged during program activities and endorsed an increased interest in anatomy as it relates to healthcare compared to prior iterations of the course. The combination of project-based learning and incorporating technologies that personalize learning experiences strengthened the CUPS mission of inspiring interest in healthcare and STEM-related fields.

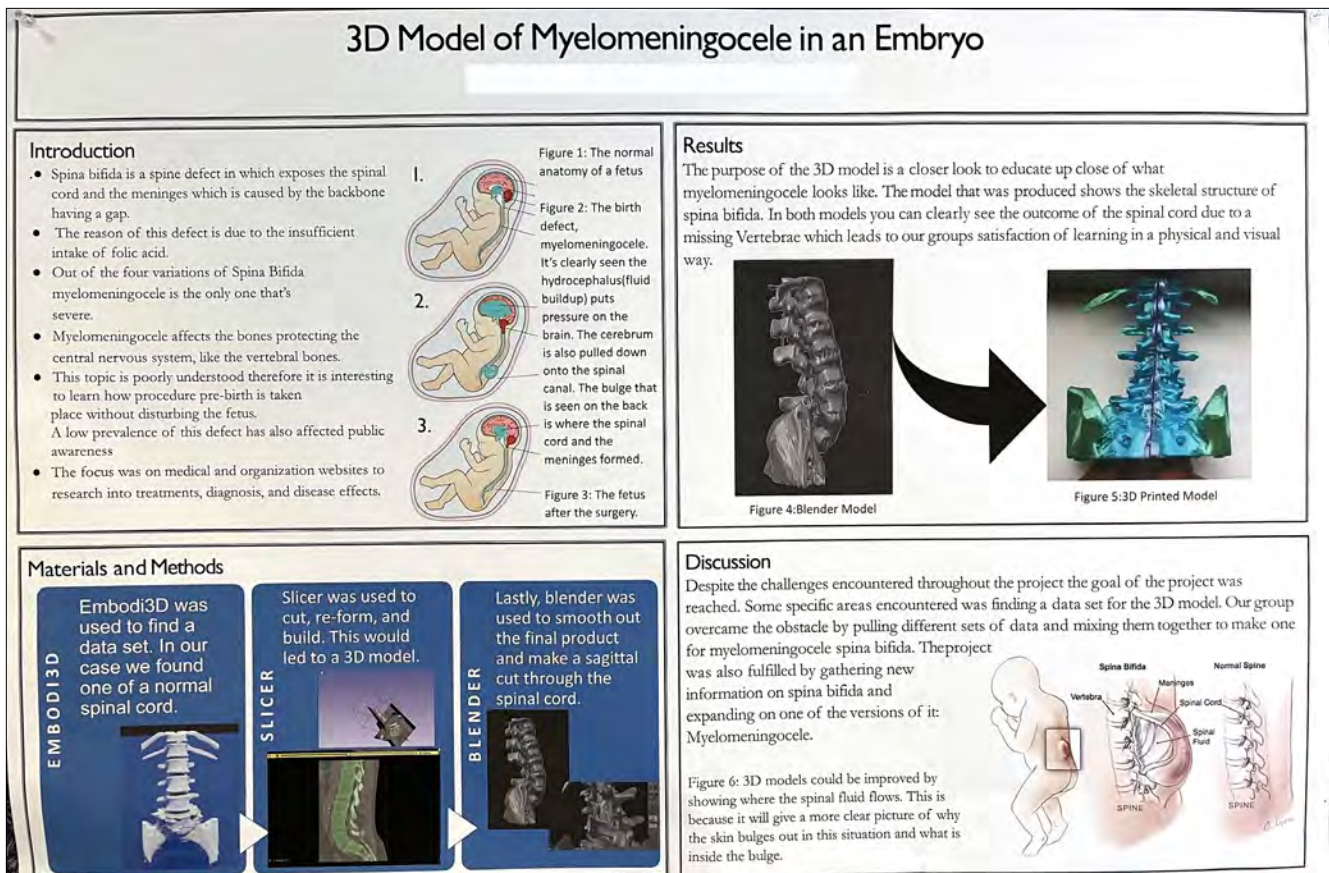


FIGURE 2. Example of a student poster modeling myelomeningocele in an embryo.

## STRENGTHS AND LIMITATIONS OF THE NEW APPROACH

### Strengths

The project-based learning approach to teaching anatomy contextualized the content relayed and exposed students to its practical applications. Additionally, it introduced students to new technologies and careers within healthcare.

Students' experience with poster presentations, 3D modeling, and printing skills can be leveraged in applications for scholarships and internships. The project-based model enabled instructors to move away from only requiring rote memorization, instead, allowing students to discover and apply anatomic principles directly. Incorporating the use of medical imaging throughout the curriculum helped introduce students to another important element of healthcare and STEM fields. Structuring projects to be completed by groups of students also provided opportunities for them to expand their communication, collaboration, and self-advocacy skills.

Temporarily shifting away from didactics directly focused on identifying anatomic landmarks to teach anatomic principles through pragmatic applications like 3D printing made

students more engaged in reported feedback. Providing students with the autonomy to choose projects they had a personal interest in, incorporating personal reflections and discussions of their chosen area of study, and providing the support students needed to execute their vision provided a more holistic experience of learning anatomy.

### Limitations

As assessed through quizzes, worksheets, and exit tickets, students demonstrated proficiency with the content relayed in each monthly workshop. Students gained a broad understanding of the four pillars of anatomy, but some did not have a deep enough understanding to develop a nuanced question to guide their summer research without guidance from educators with a background in anatomy. Additionally, due to the time between each workshop during the longitudinal year-long curriculum, many students had trouble picking up where they let off in regard to their group projects, which made advising students on their project goals more difficult. This issue was often exacerbated by a student missing a session and having a difficult time catching up on progress made during their absence. During the school year, the instructors manually kept track of attendance and used paper-based exit tickets to assess how students' engagement and retention of the material

progressed. Manually tracking student progress limited the instructors' ability to track trends related to content mastery.

The time between the year-long course and the summer curriculum made it necessary to reintroduce foundational anatomy during the summer curriculum, which subtracted from the time students had to focus on their projects. Had the instructors used a Learning Management System (LMS) to track trends in student progress, they would have been better able to target the remedial content. Instead, they provided a review of general anatomy that did not always align with student knowledge gaps or project interests. As a result, students did not have in-class time to practice 3D modeling until halfway through the summer when they were expected to begin working on their projects. This created a disconnect between the content of the classes and homework assigned in the longitudinal courses during the academic year and the summer course, which made it difficult for students to create projects that had an explicit connection to health disparities. With this, attempts will be made during future iterations of the course to concentrate on didactics and activities that focus solely on anatomy content during the academic year and reserving sessions during the summer for project development. Covid-19 and the shift to remote learning prevented the iteration and reteaching of this class in the summer of 2020, though program leadership intends to continue with the implementation of the 3D printing curriculum in person during the summer of 2022. The software used to convert medical images to 3D models and prepare models to print requires computers with processing capabilities beyond the scope of Chromebooks or other computers given to them by their schools.

## CONCLUSION

With each stage of the academic year, the CUPS anatomy course has experienced both challenges and opportunities that led to future changes in the function of the course. With the traditional model presented in the Summer of 2018, it was recognized that anatomy education for pre-collegiate students can be a very complex process that demands student engagement and interest in the material to appreciate its nature. Following the close of the Summer 2018 course, it was evident that the goals and next steps for CUPS and the anatomy course should align. One major benefit to the Summer 2019 course was the implementation of a workshop series that allowed students to build up to the summer projects, identify areas of interest, collaborate with group members, and develop many other skills valued by the CUPS program. A challenging opportunity that has already demonstrated its value is the melding of the anatomy course with the project-oriented curriculum in the presence of a newly minted makerspace.

Introducing a makerspace and a project-focused curriculum can change the approach taken in science education. The

construction of anatomic 3D models exposed students to skills and technologies that are used in surgical planning and medical education. Typically, students do not gain access to these technologies until graduate school. Despite the limitations of the course, every group successfully completed a 3D model and research poster. The students' success indicates the potential for creating other project-based anatomy classes that relate to the use of creative technologies within healthcare.

In future iterations of the Anatomy in Action curriculum, projects will be framed so there is a more explicit connection to health disparities. With this, a greater emphasis on health disparities will be made during the end of the academic year and the beginning of the summer curriculum so students can have this in mind during the brainstorming phase of their group projects.

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