

Using Digital 3D Models to Learn Physical Objects

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Abstract

The study of human anatomy and physiology typically involves an in-person laboratory component where students explore various anatomical structures through physical models and dissection. Advances in technology have enabled the development of three-dimensional (3D) models which can be observed and manipulated through a web browser outside of the lab. Oregon State University Ecampus created virtual tools for our online Anatomy and Physiology course to help online students learn the bones and features of the human skeleton. The goal of this project is to assess the ability of online students who study with 3D models to identify the same object in its physical form. This white paper discusses our study design, challenges with recruitment and collecting data, and considerations for future research.

Introduction

The study of human anatomy and physiology typically involves an in-person laboratory component where students explore anatomical structures using physical models and dissection, along with experiments to demonstrate physiology. Previously, student access to models and dissection was limited to physically attending classes in the anatomy laboratory or purchasing costly models and dissection kits for remote learning. Some components of the anatomy laboratory will never be available for at-home use, such as dissection of human donor bodies. These requirements limit access to anatomy education for online students.

Advances in technology have enabled the development of digital, three-dimensional (3D) models which can be observed and manipulated. Several studies have examined 3D technology in education. Web-based technologies have been shown to assist students in learning anatomy and physiology (Pringle and Rea, 2018). In a meta-analysis of 3D visual technology educational methods, Drs. Yammine and Violato examined the effectiveness of 3D visual technology in teaching

and learning anatomy compared to all teaching methods. They concluded that 3D visual technology is superior to 2D methods in the acquisition of anatomy knowledge among medical students (Yammine and Violato, 2014). In addition, interactive 3D digital materials have been shown to have positive effects on medical education, more than textbooks alone (Battulga et al., 2012). Outside of medical education, researchers found that 3D learning is better than 2D for performance and understanding appearance in orthographic views in an in-person graphical course in engineering (Wu and Chaing, 2012). With respect to transferable skills between digital 3D models and physical models, researchers found a positive correlation between the virtual tooth identification assessment and the real tooth identification assessment for in-person dental students (Suh et al., 2022). In this study, students learned using virtual models and were tested with both the virtual and physical models. Collectively, the evidence suggests that 3D models are effective learning tools.

While there is support for the use of digital 3D models, there have also been some inconclusive and discouraging studies regarding the value of the 3D models, especially when testing on a 2D static image (Vandenbossche et al., 2022; Preece et al., 2013, Saltarelli et al., 2014). In a study comparing human donor body use to a multimedia learning system, researchers found that the laboratory experience had a significant advantage when assessing knowledge on a physical human donor body. In this study, Saltarelli and colleagues noted the importance of including pedagogical strategies to support the transfer of knowledge to real-world situations. Additionally, spatial ability may influence the effectiveness of 3D models, especially when using 2D assessments (Vandenbossche et al., 2022), particularly in the use of a less detailed 3D model when compared to a highly detailed 2D static image. It is possible that when investigating more complex structures such as the pelvic bone, the digital model needs to be sufficiently detailed to allow for better

understanding (Vandenbossche et al., 2022). When considering learning from complex computer images such as magnetic resonance imaging (MRI), learning on a physical model was shown to be better than a digital 3D model (Preece et al., 2013). Each of these studies investigated student learning using virtual tools to supplement course materials in the face-to-face modality. Further studies are needed to investigate the ability of adults to transfer knowledge from anatomical 3D computer models used in both face-to-face and online courses to physical models with the same level of complexity and detail.

There are now a wide variety of anatomical models available both within applications and web-based programs that can be downloaded onto a smartphone, tablet or computer. Multimedia tools have great pedagogical value and enhance accessibility in a synchronous, online course (Attardi and Rogers, 2014). Subscription-based software such as Complete Anatomy and BioDigital offer detailed anatomy visualizations, but purchasing each of these increases the cost for students (3D4 Medical, 2023 and Biodigital, 2023). With web-based platforms such as SketchFab, the ability to create and share open-source 3D models is improving student access to low-cost materials that are available on-demand anywhere there is internet (Reid et al., 2020).

At Oregon State University (OSU), we have created an open access digital “[Bone Box](#)” to replicate a learning tool available to our on campus Anatomy and Physiology (A&P). This resource provides a free tool for online students which mimics the way students interact with and learn from bone models on campus. After creating the learning tool, we are investigating the ability of our college-level anatomy students to transfer the knowledge learned in the online environment using those digital 3D models, to the identical physical model. A cohort of students from the traditional face-to-face course is also being assessed for comparison. This paper shares our experiences to date in conducting this study. Data

analysis is ongoing at the time of publication of this paper.

As with any study, we have encountered challenges along the way. Participant enrollment, retention, and mailing logistics were a few challenges that will be discussed in the following sections. In addition, we present future considerations for implementing similar studies.

The Courses and Learning Tools

Courses in the Study

BI 254, Principles of Human Anatomy and Physiology (hereafter: A&P Online), is the first of a three-term online series. BI 241, Introduction to Human Anatomy and Physiology (hereafter: A&P On-campus), is also the first of a three-term series, but is offered in-person. In both 10-week courses, students explore the fundamental concepts of biology as they apply to human anatomy and physiology and examine the structures, functions, and regulatory mechanisms involved in the skeletal, muscular and integumentary systems. In terms of student experience, the primary difference in the two courses is modality and access to a physical laboratory space. An additional difference is course size. Currently, our on campus A&P course has approximately seven times the number of students as our online A&P course.

Learning Tools

In both A&P courses, students learn to identify and name the bones of the human skeleton and features of those bones (e.g., projections, holes, joint surfaces, left vs. right, etc.). In the A&P On-campus laboratory space at OSU, the primary learning tool is a box or trunk of plastic models of human bones that are unlabeled and disarticulated (i.e., disassembled skeletons). When developing the digital version of this laboratory experience for A&P Online, we worked to create a similar process and experience. The OSU Ecampus media team created a digital version of the bone trunk called the “Bone Box.” The Bone Box contains models of

unlabeled, disarticulated bones that display in random order. Students select individual bones to view and manipulate in 3D. Like in the trunk of bones in our laboratory, the randomization of the digital bones in the Bone Box requires students to familiarize themselves with the unique shapes, markings, and other features of each bone for identification purposes. In both modalities, students reference bone models, photographic atlases, and multimedia applications to discover the features and names of the bones over the course of three weeks. Students are assessed on

their ability to identify the bones and bone features during a lab practical exam. A&P On-campus assessments use bone models marked with letters and numbers while A&P Online assessments use digital models marked with letters and numbers. The process of student-led inquiry followed by practical assessment is the same in both courses (see Table 1). Historical course data indicates that students in both modalities are similarly able to display knowledge of anatomical structures when assessed in the format in which they learned.

Table 1. Comparison of bone materials, resources, timeline and assessment between A&P modalities (A&P On-campus and A&P Online).

	A&P On-campus	A&P Online
Bone Model Style	Physical Bone Trunk	Digital 3D Bone Box
Access to Bone Models	During lab and open lab ~8hr/week	24/7
Resources	Photographic atlas, full size articulated skeleton, articulated joint models, Textbook	Complete Anatomy Application, BioDigital, Textbook
Class format	Student lead inquiry	Student lead inquiry
Starting	Week 2	Week 4
Exam Week	Week 5	Week 7
Total Time with Bones	3 weeks	3 weeks
Assessment Type	Lab practical exam Fill-in-the-blank questions Physical bone models labeled with numbers and letters	Digital lab exam Fill-in-the-blank questions Digital 3D bone models labeled with numbers and letters

Study Design

We are using a pre-post test study design to compare the learning gains between course modalities. As part of their coursework, all students complete a two-dimensional (2D) Pre-test on bone and bone feature identification. Following the 2D Pre-test, students proceed with their respective course units on the human skeletal system. Participants self-selected into the course modality upon registration for classes. The primary difference in student experiences is using physical bone models in the A&P On-campus course compared to 3D digital renderings of bones in the A&P Online as described in the Learning Tools section above. After completing the units on the human skeleton, all students are assessed with a course-based midterm exam and the 2D Post-test. Students who consent to study participation take an additional bone assessment: a 3D Post-test. The study timeline for each course is outlined in Table 2.

2D Pre-test. Baseline knowledge of bone and bone feature identification is assessed using a 2D Pre-test on Qualtrics XM® prior to beginning the course unit on the bones and bone features. This 16-question fill-in-the-blank assessment requires

students to identify bone names and features using 2D images marked with leader lines and letters (see Figure 1). Students are instructed to complete the pre-test using their current knowledge and no resources (see Appendix A).

2D and 3D Post-tests. After completion of course units on the human skeletal system and completion of an associate midterm exam, acquired knowledge of bone and bone feature identification is assessed with two methods. First, all students repeat the same 2D test that they take at the start of the courses (see Appendix B). Study participants also complete a 3D Post-test. This 19-question fill-in-the-blank paper-based assessment requires participants to identify bone names and features using physical bone models marked with numbers and letters. Participants enrolled in A&P On-campus sit for a proctored test in our lab space with the physical bone models, an exam sheet, and written instructions (see Appendix C). Participants enrolled in A&P Online are mailed a box with the same physical bones, exam sheet, written instructions (see Appendix D), and are proctored by a member of the study team via Zoom. A&P Online participants are instructed not to open the mailed box prior to the proctored exam and proctors confirm compliance with this instruction.

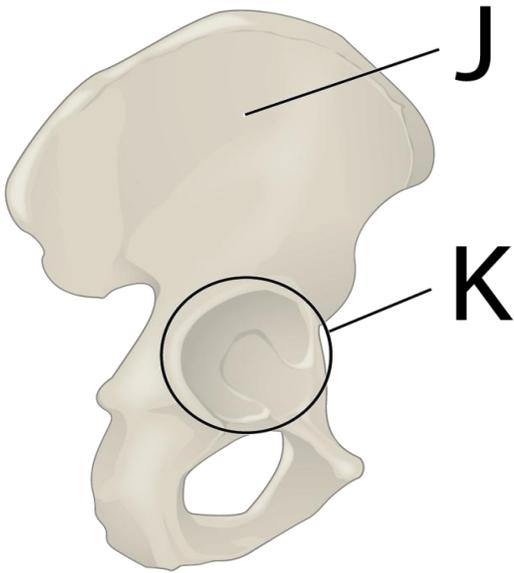
Table 2. Timeline and assessments included in the study.

	A&P On-campus	A&P Online
Recruitment*	Pre-term	Pre-term
2D Pre-test	Week 1	Week 1
Begin Bone Content	Week 2	Week 4
Lab Exam	Week 5	Week 7
2D Post-test	Week 6-10	Week 8-10
3D Post-test*	Week 6-10	Week 8-10

Note: Weeks are based on Oregon State University's 10 week fall term schedule.

** Indicates items completed by study participants only. All other assessments are assigned to all students enrolled in both A&P courses.*

Figure 1. Example image from 2D Pre- and Post-tests.



Lessons Learned to Date

Success in Proctoring

The final assessment in the study is a 3D Post-test proctored by members of the research team. To date, the protocols for proctoring exams have been successful. Participants are sent a schedule with 30-minute appointment slots and self-select their testing window. Only three participants were unable to attend their scheduled appointment but were rescheduled within a week. A&P Online participants are proctored over Zoom while A&P On-campus participants are proctored in our lab space at OSU. All participants, including A&P On-campus, were presented the study materials in the same 2-layered shipping packaging, including labeled bone models and a blank answer sheet. All 3D Post-tests were completed in under 20 minutes. This method provides equivalent testing conditions and has been efficient for the study team to administer.

We recommend, in future studies, researchers should provide a wide variety of proctored exam appointments that includes various times of day

and days of the week to accommodate participant schedules, especially when working across multiple time zones. We suggest planning for rescheduling by providing time slots at the beginning of the desired testing window initially. After scheduling all participants, researchers can make the time slots at the end of the testing window available to accommodate schedule changes.

Challenges in Student Recruitment

To date, participants were recruited from students enrolled in A&P On-campus and A&P Online via course announcements and email. Initial recruitment took place in the week prior to the start of Fall term 2024. We aimed to recruit 20 participants from each course. Because our initial study enrollment was low, a second round of recruitment and data collection occurred in the Fall of 2025. The following is a description of our recruitment process including challenges we have encountered so far.

To recruit participants, an email is sent at the start of the term to all students in both courses. Students are told that participation is voluntary and does not affect course grades. Participation is incentivized with a \$25 gift card to Amazon upon study completion. Eligible individuals are enrolled in the study after obtaining informed consent. Individuals who are not enrolled in either A&P On-campus or A&P Online are excluded from the study. Additionally, individuals who had taken a university-level human anatomy and physiology course within the past five years are excluded.

Due to differences in course size, participant enrollment has so far been unequal for our two courses. We initially aimed to recruit 20 participants from each course. In response to our recruitment advertising during Fall 2024, 37 students emailed to express interest in participating (A&P On-campus $n = 23$, A&P Online $n = 14$). After excluding ineligible individuals, we enrolled 25 participants (A&P On-campus $n = 17$,

A&P Online n = 9). Of these, 21 participants have completed all study requirements (A&P On-campus n = 15, A&P Online n = 6). Participant interest, enrollment, and completion are shown in Table 3. Because the number of student participants who completed all study requirements are well below our recruitment goals, we collected data in Fall 2025 courses. Analysis is in progress at the time of publication.

This study was designed to fit largely within existing course structures. The initial recruitment email garnered sufficient interest for A&P On-campus enrollment. To increase the response rate for A&P Online, the recruitment email was followed up by additional course announcements. On the Pre-test, students in both courses are asked “Are you enrolled in the study, Using 3D Models to Learn Physical Objects?” Students who were not enrolled but answered “Yes” are sent a follow-up email with links to the informed consent and demographic survey. Despite our recruitment efforts to date, we have been unable to garner sufficient participation from A&P Online students. If we were to repeat this study, we would consider adjusting our recruitment strategy for the online students. Instead of recruiting via announcements, which required students to proactively reach out to our team via email, we would embed

recruitment into the 2D Pre-test which is part of the required course materials.

The 2D Pre-test could include study information, an interest question, screening questions triggered by a positive interest response, and a consent form if eligibility requirements are met. With this design, all students would opt in or out of participation during a required course interaction, instead of relying on students reading an announcement and drafting an email to the study team.

Our initial target recruitment numbers may have been unrealistic. The significant difference in course sizes may have impacted recruitment. For example, if we recruited twenty participants it would have represented 40% of A&P Online students, but the same number of participants would have represented only 6% of A&P On-campus students. Our sample size has been further depleted through attrition. To date, two participants from each course stopped responding to emails and did not complete the final 3D assessment. However, these four individuals did complete their respective A&P courses. One additional participant from the A&P Online course did not complete study due to a shipment issue detailed below. In Fall 2025, we experienced the same recruitment challenges in the A&P Online course.

Table 3. Study interest, enrollment and completion data for A&P On-campus and A&P Online in the first round of data collection in Fall 2024.

	A&P On-campus 2024	A&P Online 2024
Course Total (n)	343	50
Interested	23 (6.7% of course)	14 (28.0% of course)
Enrolled	17 (5.0% of course)	9 (18.0% of course)
Completed	15 (4.4% of course)	6 (12.0% of course)
Completion Rate	88.2%	66.7%

Conducting research with student participants that involves a time commitment beyond the scope of the course presents challenges for both recruitment and representative sampling. Previous OSU Ecampus researchers have encountered this problem with recruitment from an online course (e.g., Kesterson and Loges, 2023). When designing a study that includes time outside of class, we think additional incentives are necessary. The incentive for completing this study (\$25 Amazon gift card) appears insufficient to encourage enrollment. Participation in this study did not impact student grades in any way; we did not provide extra credit to study participants. Perhaps including a grade-related incentive like extra credit, with alternate extra credit options for non-participants, would encourage study participation. Additionally, emphasizing the low time commitment (only a scheduled 30-minute post-test) may encourage more students to participate. Other researchers have had more success with recruitment of online students by having participants complete all study activities as part of their coursework (Bushnell & Harrison, 2025). However, in this study, the online course design and modality do not allow for mailing physical models and individually proctoring exams for all 50 students, thus requiring a commitment from participants beyond the expectations of the course.

When designing studies that include online students, we recommend recruiting participants from multiple sections or terms to potentially offset recruitment challenges due to smaller class sizes and attrition. Careful consideration should be given to how researchers incentivize student participation in study-related activities that require a time commitment outside of class.

Successes and Challenges in Shipping Study Materials

Models for the 3D Post-test are shipped to online participants. To maintain the integrity of the 3D Post-test, we use a two-layered seal method. The labeled bones are placed in an internal envelope

with a label across the seal which read, “STOP. Wait for your proctor to open.” That envelope is placed inside the primary shipping box which has the same warning label on the outside. To date, we have had 100% compliance with these instructions.

To investigate physical models with students around the state, country, or even world, researchers need to be well prepared to ship study materials. When shipping materials, there is a risk of loss due to shipping-related damage or a participant failing to return items. Anticipating that damage to the bone models may occur, and/or that the labels may become displaced, we pre-mark the label locations with pencil dots and put the label sticker over the dot. In the event a label came off, the dot allowed for the proctor to direct the participant where to place the sticker. In our experience to date, only one label has come off in transport. Most participants have returned their study materials as planned. However, one skull was damaged on the return shipment. Additionally, two participants failed to return the bone models after dropping from the study.

Researchers should also account for the time needed to prepare research materials prior to shipping. Labeling and packing models and preparing shipments (including return labels) can take several weeks. Researchers should prepare for this in their shipment timeline, working backwards from desired delivery date. Researchers may also encounter problems with international shipping. For example, we shipped bones to an international participant while their country's post was on strike. This international package was delayed by months resulting in our international participant not being able to complete the study.

Recommendations

Online learning provides critical access to higher education for many individuals. With this newer modality, we need to create course elements and structures which enable our online students to achieve learning outcomes. Comparative

assessments of online and on campus students are critical to determining whether we are achieving our goal of equivalent learning gains and transferability of online learning. By assessing the efficacy of our learning tools, we can identify whether shortcomings exist and make data-driven decisions to support student success. Collecting data that demonstrates transferability of online skills and knowledge will build evidence for acceptance of online programs and support students in their career paths.

Before embarking on research in online education, it is critical to know the student population. In our experience, online learners are juggling many responsibilities that constrain their time. As such, their bandwidth is limited. Taking on optional opportunities, while interesting to them, may not fit in their schedules. When designing a study, our recommendation is to limit participant engagement beyond course activities. Researchers should consider integrating all aspects of the research project into the course design when possible. This allows the research team to recruit participants using class-first language instead of research-first language. For example, asking students for permission to use their course activities for research (class-first) versus asking students to participate in research activities outside of class (research-first). It may also incentivize student participation if the activities are already required for the course.

When a research project requires non-course components, we recommend designing incentives that bear course credit (e.g., extra credit). For equity when including course credit, we suggest researchers provide an optional alternative assignment designed to take a similar amount of time for students who elect not to participate in the study. For example, if study participants are awarded extra credit for completing a 30-minute assessment, other students could earn the same extra credit by writing a short paper or creating a study tool. We believe that students may be more motivated by course credit than by small monetary

compensation, particularly in challenging courses. If offering extra credit for study participation, also consider timing recruitment early in the academic term. Early term extra credit opportunities appeal to a broad swath of students, where late term extra credit opportunities may differentially appeal to high and low performing students.

Finally, we recommend taking class size into consideration when designing for statistical analysis. In smaller courses, it may be more challenging to enroll enough participants to power analyses and may warrant running the study over multiple terms or concurrent course offerings. We believe the additional time needed to recruit enough participants is worth the effort to improve our online teaching and help our students move forward confidently in their career paths.

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Appendix A

Student/participant instructions for 2D Pre-test

In this assessment, you will be asked to identify bones and features of the human skeleton. This is a pre-test of your current knowledge. Please do not use any resources for this assessment. Do not study in advance. We would like to know what you know right now, before studying the skeletal system. You will receive full credit for attempting this assessment, it is not scored based on correct answers. For any question, if you do not have an answer or a guess, we prefer for you to leave the question blank.

If you are enrolled in the study "Using 3D Models to Learn Physical Objects", please have your participant ID ready. This assessment fulfills the 2D Pre-test requirements of the study.

Appendix B

Student/participant instructions for 2D Post-test

In this assessment, you will be asked to identify bones and features of the human skeleton. This is a post-test of your current knowledge. Please do not use any resources for this assessment. We would like to know what you know right now, after studying the skeletal system. You will receive full credit for attempting this assessment, it is not scored based on correct answers. For any question, if you do not have an answer or a guess, we prefer for you to leave the question blank.

If you are enrolled in the study "Using 3D Models to Learn Physical Objects", please have your participant ID ready. This assessment fulfills the 2D post-test requirements of the study.

Appendix C

Participant instructions for in-person 3D post-test

For this test, you will need to refer to the set of labeled bones that have been provided for you. Please answer each question with the name of the bone, bony structure, or side of the body (left or right) as indicated in the question. Do not use "the" in your answer.

Note: If you are unable to find a label or if a label has fallen off, please ask your proctor. They will help you determine where the label should be placed.

Appendix D

Participant instructions for online 3D post-test

A pre-paid shipping label is included in this box. Once you have completed your proctored post-test, please place the bone in the bubble envelope and return them to the box they arrived in. Use the included packing tape to securely close the box and affix the prepaid shipping label. You can return the package by dropping it off at your local US Post Office. Thank you!

Exam Notes:

For this test, you will need to refer to the set of labeled bones that have been provided for you. Please answer each question with the name of the bone, bony structure, or side of the body (left or right) as indicated in the question. Do not use "the" in your answer.

Note: If you are unable to find a label or if a label has fallen off, please ask your proctor. They will help you determine where the label should be placed.

When you finish the test, you will be asked to show your answer sheet to the proctor and they will take a screenshot of your answer sheet. In addition, please take a picture of your completed answer sheet and email it to a member of the study team.

About the Research Unit at Oregon State Ecampus

Vision

The Ecampus Research Unit strives to be leaders in the field of online higher education research through contributing new knowledge to the field, advancing research literacy, building researcher communities and guiding national conversations around actionable research in online teaching and learning.

Mission

The Ecampus Research Unit responds to and forecasts the needs and challenges of the online education field through conducting original research; fostering strategic collaborations; and creating evidence-based resources and tools that contribute to effective online teaching, learning and program administration.

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