Building Confidence: Engaging Students Through 3D Printing in Biology Courses

Courtney Guenther, PhD[1], Matthew Hayes, PhD[2], Andrew Davis, MFA[3], and Matthew Stern, PhD[4]

1Assistant Professor, Department of Biology, Winthrop University, Rock Hill, SC 29733
2Professor, Department of Psychology, Winthrop University, Rock Hill, SC 29733
3Instructor, Department of Fine Arts, Winthrop University, Rock Hill, SC 29733
4Associate Professor, Department of Biology, Winthrop University, Rock Hill, SC 29733

Abstract

3D printing is a widely used technology in a number of STEM fields and can be incorporated into undergraduate education in order to engage students in active learning. Using the Technological Pedagogical Content Knowledge (TPACK) framework, this study examined student perceptions of completing 3D printing of a physical model in two different Biology courses, Anatomy and Physiology and Molecular Biology. Students completed surveys before and after engaging in a semester-long 3D printing project. Demographic information was also collected in order to assess student perceptions based on race and sex. Students reported increased confidence with 3D printing technology after completing their projects, and this effect occurred similarly across race and sex. Student attitudes towards their 3D printing experience were overwhelmingly positive, with general interest and excitement being the most common themes. These results suggest that 3D printing projects can be successfully implemented in undergraduate courses and generate positive student outcomes. Engaging women and underrepresented minority students with 3D printing technology may have significant implications for retention of these students in STEM programs.

Keywords: undergraduate, 3D printing, models, anatomy and physiology, molecular biology

Introduction

The goals of Vision and Change in Undergraduate Education include ensuring that undergraduate Biology courses are “active, outcome-oriented, inquiry-driven, and relevant” (AAAS, 2009). The use of active learning strategies has been shown to improve student learning and exam performance and reduce failure rates (Freeman et al., 2014). 3D printing is an active learning tool that is increasingly being utilized in both K-12 and higher education, where it has been applied across disciplines ranging from STEM to the arts and humanities (van Epps et al., 2015). There is rapid growth in careers related to 3D printing and a demand for skills in this field, which can be introduced in undergraduate curricula (Pernaa & Wiedmer, 2019). For biology and pre-health students, applications of 3D printing, including scientific research, biomedical engineering, medical device design, industrial manufacturing, and personalized medicine, are closely related to many of the existing and emerging careers that they intend to pursue (Bhatt & Szalinski, 2013).

The pedagogical rationale for this study is grounded in using modeling and simulations as outlined in the AAAS Vision and Change Core Competencies and Disciplinary Practice (AAAS, 2009), “Drawing-to-learn” with the use of technology (3D printing) to develop the drawing (Cromley, 2020), and the Technological Pedagogical Content Knowledge (TPACK) framework, which has been used extensively to assess the incorporation of technology into pedagogy (Pernaa & Wiedmer, 2019). While TPACK is widely used, its application to studies on 3D printing is not well established. To address this gap in knowledge, we examined student perceptions after actively engaging in 3D printing of a physical model. Our design allowed for evaluation of “pedagogy, technology, content, and their interaction at the same time” (Pernaa & Wiedmer, 2019). Our goal was to introduce students to 3D printing technology through instructor-guided inquiry, so that the students could print an object of their choosing based on a publicly available template. They then utilized their 3D model during class presentations in order to enhance three-dimensional understanding of one of their course concepts. The project was carried out in two different courses that target different student populations and address two different levels of biological scale: 1) a sophomore-level Anatomy and Physiology course sequence for non-Biology majors and 2) a combined undergraduate and graduate level Molecular Biology course taken by Biology and Biochemistry majors. Our project design is noteworthy because most previous references to the use of 3D printing in Anatomy and Physiology and Molecular Biology/Biochemistry involved a more passive incorporation of 3D printing – the use of non-student generated 3D printed artifacts to aid teaching/learning of a particular subject (Ford & Minshall, 2019). In our study, students actively selected their object to print, engaged directly in the 3D printing process, and applied their object to course material through in-class presentations.

3D Printing in Anatomy and Physiology

Use of physical 3D models to teach Anatomy significantly improves student performance during assessment compared to the use of textbooks and 3D computer models (Preece et al., 2013) and compared to virtual and physical organ dissection (Lombardi et al., 2014). Students also report increased levels of confidence after using physical 3D models (Preece et al., 2013). 3D printing provides one mechanism to use physical 3D models and has been integrated into Anatomy and Physiology education in a variety of ways including 3D printing replicas of human bones (AbouHashem et al., 2015), skeletal structures from different species (Thomas et al., 2016), and human cadaver prosections (McMenamin et al., 2014; Fredieu et al., 2015). Although there are a number of studies that have used 3D printed models in anatomy education, we are unaware of any that incorporate the actual process of 3D printing in an undergraduate Anatomy and Physiology course so that students gain direct experience with 3D printing technology. Therefore, this study explored student perceptions before and after completing a project that required learning the 3D printing process to produce a student-chosen anatomical model that was then used to help show and explain relevant anatomy to peers during a presentation on a clinical disorder.

3D Printing in Molecular Biology and Biochemistry

Molecular biology and biochemistry courses typically emphasize the connection between biological structure and function and often do so in the context of examining biological information flow and transformations of energy and matter at the molecular scale (AAAS, 2009, Brownell et al., 2014). However, three-dimensional structure-function relationships at molecular scale are difficult for students to visualize and comprehend (Tibell & Rundgren, 2010, Forbes-Lorman et al., 2016, Offerdahl et al., 2017). Tools such as physical ball-and-stick models and virtual models within software that allow students to visualize and manipulate molecules on a computer screen are widely used in chemistry, biochemistry, and molecular biology courses and have been shown to increase student learning related to structure-function relationships (Harris et al., 2009, Jaswal et al., 2013, Newman et al., 2018). 3D printing represents an additional option for generating detailed physical models that provide students with the opportunity to visualize and interact with molecular scale structure-function relationships.

3D printing has been used in molecular-scale courses in a variety of ways (Pernaa & Wiedmer, 2019, Pinger et al., 2020), including providing 3D printed models for students to handle and manipulate in order to emphasize particular structure-function relationships (Cooper & Oliver-Hoyo, 2017; Howell et al., 2018; Babilonia-Rosa et al., 2018) and students generating 3D printed objects related to a specified area of emphasis within a lab course (Meyer, 2015). There are fewer reported examples of an instructor-guided inquiry project approach similar to the one we employed where students in a non-laboratory molecular biology course were able to learn and apply the 3D printing process to the production of an object of their choosing that could be used to show and demonstrate molecular-level structure-function relationships to peers during a presentation of their individually written review papers (Letnikova & Xu, 2017).

Demographic Considerations

Gender differences in spatial ability have been previously reported, with women exhibiting lower abilities compared to men. These differences may be accounted for, at least in part, by cultural influence and years of education (Hoffman et al., 2011). For example, utilization of a 3D physical model in a cell and molecular biology course increased quiz scores for female students, but not male students. Women also self-reported greater understanding of molecular structure/function connection after using 3D physical models (Forbes-Lorman et al., 2016). Therefore, integration of 3D printing in undergraduate education may be experienced differently and/or show varied impact across demographics. Given the importance of spatial ability to understanding key concepts within STEM courses, incorporating 3D printing into undergraduate programs may have even greater implications for retaining women and underrepresented minorities in STEM programs. Therefore, this study also explored student confidence and attitudes toward 3D printing in STEM courses across demographics. We hypothesized that after a semester-long 3D printing project, students across demographics would report increased confidence with using 3D printing and a positive attitude towards this technology in both Anatomy and Physiology and Molecular Biology courses. We also predicted that students would report increased learning of course content based on the 3D printing experience.

Methods

Participants

The participants were undergraduate students and MS seeking graduate students at a public primarily undergraduate institution in South Carolina. Students were recruited from sophomore level Anatomy and Physiology courses (Summer 2019 and Fall 2019 semesters) or an upper-level combined undergraduate/graduate Molecular Biology course (Fall 2019).

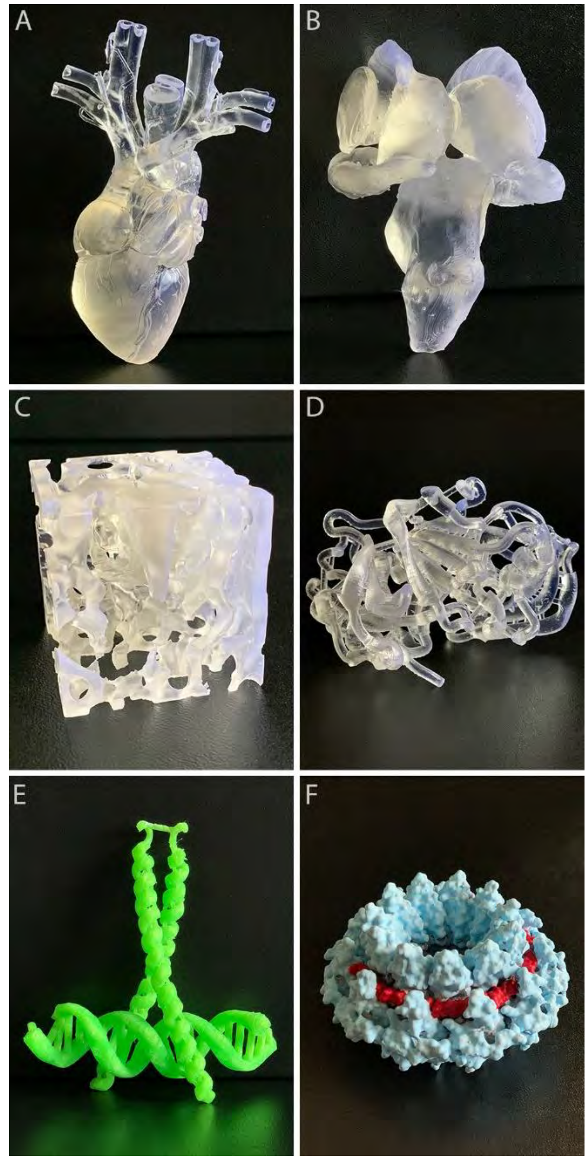
Procedure

Students were provided details of the project and recruited to participate in the study during the first week of class. All students completed the 3D printing project regardless of participation in the research study. Students were assigned a random 6-digit number to be used to match survey responses at the beginning and end of the semester, and those who agreed to participate completed an online survey via Qualtrics (Qualtrics, Provo, UT and Seattle, WA) at the beginning and the end of the term. The survey consisted of three sets of questions (Appendix A and B). The first set measured perceptions of 3D printing with two questions; interest in and confidence with 3D printing were measured using a 5-point Likert scale. The second set of questions measured attitudes toward 3D printing technology using an open-ended question and a set of 10 Likert questions that used a 5-point scale. The Likert questions were only administered at the end of the term and were grouped to measure the ease of use and usefulness of 3D printing technology (2 items; Cronbach's $\alpha = .57$), the perceived value of 3D printing to student learning (6 items; $\alpha = .84$), student desire to see other courses incorporate 3d printing technology (1 item), and how challenging the 3D printing process was (1 item). The final set of questions included demographic questions that were designed to capture diversity and inclusivity within the student population (Fernandez et al., 2016; The Human Rights Campaign, 2019). Anatomy and Physiology

In Anatomy and Physiology courses, students were assigned to groups of four or five using course averages to ensure a mix of academic performance in each group. Each group selected an organ or structure to 3D print and relate to a clinical disorder of their choosing (Appendix C). All objects were

Figure 1

Example 3D Prints



Example 3D Prints

Models printed in Anatomy and Physiology include heart (A) (MAAS Collection, 2016) and subcortical brain structures (B) (Kessler, 2015). Models printed in Molecular Biology include osteoporotic bone (C) (Barak & Black, 2018), ribbon models of the BACE1 enzyme (D) (Kuglstatter et al., 2008), the bZIP regions of a CREB dimer bound to DNA (E) (Schumacher et al., 2000), and a surface model of the RAD52 protein with ssDNA bound to its inner DNA binding site that was painted by the student (F) (Saotome et al., 2018).

printed using a Form2 printer and clear resin (Formlabs, Somerville, MA). Printing costs were covered by course fees. Students obtained .stl files from www.thingiverse.com, https://www.embodi3d.com, or https://3dprint.nih.gov, which all maintain creative commons copyright licenses. PreForm software (Formlabs, Somerville, MA) was used to scale and process the prints. Prints were post-processed in a 91% isopropyl alcohol rinse for 2 minutes, and then transferred to new 91% isopropyl alcohol and soaked overnight. Rafts and supports were removed after rinsing. Students delivered a group presentation about the model and its connection to a clinical disorder (Figure 1A and B).

Molecular Biology

In Molecular Biology, each student was required to 3D print an object to aid in the presentation of their individually written review paper on a topic of their choosing (Appendix D and E). While most students used the NIH 3D Print Exchange to find or generate a file for 3D printing as described below, students had the option to use any file that they could find or create. 3D printing was completed using a Form2 or a FlashForge Creator Pro printer with clear resin or PLA filament, respectively (Figure 1C-F). Printing costs were covered by grant funding or by the student (students could keep the object if they purchased it at cost).

A single class period held in a computer lab was designated to provide students with an overview of the 3D printing workflow. Students were assigned to read the Beltrame, et al. JoVE paper (2017) and watch the associated video prior to class. During class, students were introduced to fused deposition modeling (FDM) and stereolithography (SLA) 3D printing via YouTube videos. Students then practiced using the NIH 3D Print Exchange to find existing .stl files or import Protein Data Bank (.pdb) files and generate .stl files for sequential downstream processing in Autodesk Netfabb and Autodesk Meshmixer as described in Belatrame, et al. (2017). Both software are freely available. A live demonstration of the recommended processing steps and instructions for acquiring the processing software were provided in class. Processed .stl files were imported into PreForm for printing on the Form2 or Simplify3D for printing on the Creator Pro. These software slice the model and generate the code for printing according to the print settings input by the user. Form2 automatically adjusts temperature and UV laser settings based on the resin used and applies all settings to the gcode. The user adjusts the print resolution, and most students chose 25 microns for the finest resolution. Print settings recommended in Beltrame, et al. (2017) were used for printing on the Creator Pro. Form2 prints were post-processed as described above. Post-processing of Creator Pro and Form2 prints consisted of removal of the raft and supports.

Data Analysis

Data were analyzed using Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA) and SPSS Statistics (IBM, Armonk, NY). Students were asked to enter their 6-digit number on both the pre- and the post-survey to preserve anonymity. Unfortunately, 21 students entered the incorrect number or completed only one of the surveys, resulting in the inability to match several students' pre- and post-surveys. We report analyses on the full data set because some data (the attitudes toward 3D printing) were only administered at the end of the term, and we wanted to conduct the other analyses on the full sample as well. Analysis on the matched data produced qualitatively similar results. Primary analyses were a series of 2 (Course: Anatomy and Physiology, Molecular Biology) X 2 (Time: Pre, Post) between-subjects ANOVAs and t-tests on the survey items and $\chi 2$ analyses on the student comments. All statistical tests were conducted where $p < .05$ was considered significant. All values were reported as a mean ± standard deviation.

Results

Participants

Of the 131 responses, 67 came from the pre-survey and 64 from the post-survey. As a whole, participants were mostly women (n = 101, 77.1%) and most commonly identified as White (n = 80, 61.1%) or Black/African American (n = 28, 21.3%). Race was dichotomized as white or minority (students reporting one or more minorities). Table 1 presents race and sex breakdown in the pre- and post-surveys.

Student Confidence with 3D Printing

Students in both courses reported increased confidence with the 3D printing process in the post-compared to the pre-survey, $F(1, 127) = 39.14$, $p < .001$, Cohen's $d = 1.09$ (Figure 2A). While students in Molecular Biology had marginally higher confidence overall, $F(1, 127) = 3.61$, $p = .06$, $d = 0.24$, the increase in confidence from pre- to post-test was the same for both courses, $F(1, 127) < 1$, $p > .05$, and also occurred in both white and minority women,

Table 1.

Participant Demographics

	Pre Survey		Post survey	
Race/ethnicity	**n**	**Percentage**	**N**	**percentage**
White	41	61.2	40	62.5
Minority	26	38.8	24	37.5
Sex				
Male	16	23.9	13	20.3
Female	50	74.6	51	79.7
Not answered	1	1.5	0	
Total	67		64	

ts > 4.37, ps <.001, ds > 1.47, (Figure 2B). There was no difference between white and minority women in this effect, F(1, 97) = 0.06, p = .80. This increase in confidence was specific to 3D printing; students didn't report significant changes in confidence with technology generally, all Fs < 1.27, ps > .26.

Student confidence with 3D printing

Student confidence with 3D printing increases with completion of a 3D printing project. (A) Students in both courses reported increased confidence in 3D printing, Fs > 3.60, ps < .06, ds > 0.23. (B) Minority women and white women reported significant gains in confidence, ts > 4.37, ps < .001, ds > 1.47; the magnitude was the same for both groups, F(1, 97) = 0.06, p = .80.

Student Attitudes towards 3D Printing in Biology Courses

Overall, students had high ratings for ease of use (3.70 + 0.84), value to learning (3.97 + 0.69), and believed that more courses should incorporate 3D printing technology (3.88+1.03; see Table 2). These ratings didn't differ by course (ts < 1.28, ps > .20). We then examined whether attitudes differed for underrepresented groups. Ratings were as high for women as for men (ts < 1, ps > .48) and were the same for white and minority students (ts < 1.26, ps > .21). Students rated the challenge of the 3D printing process as intermediate (2.63 + 1.02; see Table 2), and these ratings didn't differ based on race or gender (ts < 1.28, ps > .20). Students in Molecular Biology (3.24 + 1.30) rated the 3D printing process as more challenging than students in Anatomy and Physiology (2.40 + 0.80), t(62) = 3.08, p = .003, d = 0.87.

Figure 2.

Student confidence with 3D printing

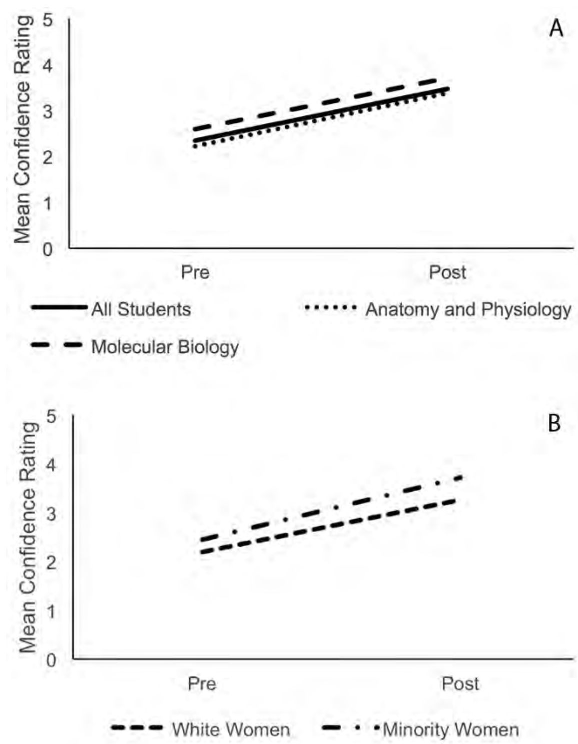


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Table 2.

Likert scale responses to 3D Printing.

	Ease of Use and Usefulness of 3D Technology		Value to Learning		Include 3D Printing in More Courses		Challenging	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
All students	3.70	0.84	3.97	0.69	3.88	1.03	2.63	1.02
Course								
Molecular Biology	3.88	1.04	4.15	0.81	4.00	1.12	3.24	1.30
Anatomy and Physiology	3.64	0.76	3.90	0.63	3.83	1.01	2.40	0.80
Sex								
Male	3.65	1.09	3.94	0.89	3.69	1.25	2.31	1.03
Female	3.72	0.78	3.98	0.64	3.92	0.98	2.71	1.01
Race/Ethnicity								
White	3.65	0.83	3.90	0.65	3.75	1.01	2.75	1.03
Minority	3.79	0.87	4.09	0.75	4.08	1.06	2.42	0.97

Note. 1 = *Strongly Disagree*, 2 = *Agree*, 3 = *Neither Agree nor Disagree*, 4 = *Agree*, 5 = *Strongly Agree*

Student Responses to Open-Ended Questions

Students made overwhelmingly positive comments, and the tone of the comments was the same at the beginning and end of the term, $\chi2(2, N = 109) = 1.48$, $p = .48$ (Table 3). General interest or excitement about 3D printing was the most common theme mentioned by students. Only references to having or lacking prior experience with 3D printing were more frequent at the beginning of the semester relative to the end of the semester; all other comments occurred in similar proportions at both times,

$\chi2(3, N = 187) = 8.47$, $p = .04$, which was a small effect, Cramer's $V = .21$.

Discussion

This study examined student perception of the inclusion of a 3D printing project in Anatomy and Physiology and Molecular Biology courses at a public primarily undergraduate institution. Students in both courses reported a large increase in confidence with 3D printing after completing the project, and this increase in confidence was demonstrated in both underrepresented minority women and white women. Additionally, students indicated that the 3D printing project added high value to learning, was generally easy to use, and should be incorporated into more courses. Students also reported overwhelmingly positive comments about 3D printing, with general interest or excitement reported the most frequently.

Comparisons made between Anatomy and Physiology and Molecular Biology courses demonstrated marginal differences. Molecular Biology students had a slightly greater increase in confidence with 3D printing and rated the 3D printing process as more challenging compared to Anatomy and Physiology students, which is not surprising considering the differences in the 3D printing projects between the classes. Molecular Biology students had a longer 3D printing workflow and worked individually, while Anatomy and Physiology students had a shorter 3D printing workflow and shared responsibilities between group members. Differences between these courses may also be related to the target student population, as Anatomy and Physiology students included non-Biology majors and primarily underclassmen, while Molecular Biology students included junior and senior Biology and Biochemistry majors, as well as Biology Masters students.

As noted in previous studies in Anatomy and Physiology, one of the advantages in utilizing 3D printing technology is the ability to create models that may not otherwise be available or may be costly (AbouHashem et al., 2015; Thomas et al., 2016). Similarly, in our study, students were able to print anatomical models that are not typically available in an undergraduate lab, such as the subcortical brain structures model. Likewise, in Molecular Biology, the models our students printed that were connected to their review paper cannot be purchased. This creates

Table 3.
Qualitative responses to 3D Printing.

Comment Characteristic	Pre (*N* = 57) *n*	Pre %	Post (*N* = 52) *n*	Post %	*Sample Comments*
Tone					
Positive	49	86.0	41	78.9	"I am interested and excited to use 3D printing technology."
Neutral	3	5.3	6	11.5	"It was something new and different."
Negative	0	0	0	0	
Mixed	5	8.8	5	9.6	"I do not feel strongly about 3D printing, however it does seem like something that could be interesting but also intimidating as it is something I have not done before."
Theme					
General interest or excitement	49	86.0	46	88.5	"I think this will be a very cool experience."
Understanding concepts or how to use technology	16	28.1	22	42.3	"3D printing is relatively simple, but it is a hassle having to have so many different programs to complete the work. The post-processing of taking off the base and supports is more simple and fun than it appears."
Applying 3D printing to a course or profession/medicine	15	26.3	24	46.2	"3D printing is very useful in many aspects of the world. The main area that I have heard of 3D printing being used is in the medical field."
Prior experience with 3D printing	12	21.1	3	5.8	"it was something new and different."

Note. Each comment was evaluated separately for tone and for themes. Tone categories were mutually exclusive, but a comment could contain multiple themes.

a unique opportunity for students to create models that not only benefit their individual learning experience, but also add to the lab/course collection of resources that will enhance learning for future classes.

Increased confidence after completion of the 3D printing project reported by minority and white female students is a significant finding and has broader implications for retaining women in STEM programs. Previous research has found that women generally perceive themselves as academically weaker compared to men, including lower confidence in their academic abilities, even though they perform similarly to their male counterparts when their academic skills are tested objectively (MacPhee et al., 2013). The long-lasting repercussions surrounding academic self-efficacy may include leaving STEM programs and lack of entry into STEM careers (MacPhee et al., 2013). Our findings of improved self-efficacy by actively engaging with new technology in the classroom are encouraging and this was noted by female student comments in our surveys, particularly as it relates to visual-spatial perception:

> "This was a great opportunity to see smaller creations come to life. I really enjoyed finding a model, picking it out and being able to see a smaller replica of what I chose. I believe this a great advancement towards technology, research, and future medical breakthroughs."

> "I think that 3D printing is a great resource, especially for STEM classes, in that you can see and manipulate the object that you are trying to study. This project was very helpful, and I think it is a great project to continue in other classes."

Future Directions

The focus of this study was to examine student perceptions surrounding their 3D printing experience; therefore, we did not quantify the effectiveness of our 3D printing projects on student learning through objective assessments such as exams or quizzes. Future research will examine how 3D printing impacts learning gains through controlled assessments of relevant course concepts and content.

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Appendix

APPENDIX A: QUALTRICS PRE-SURVEY

PLEASE ANSWER THE FOLLOWING QUESTIONS.

1. Student Code (as provided by the instructor):_____________

2. Which course are you taking?
   a. Molecular Biology
   b. Anatomy and Physiology
   c. Cell Biology

3. Do you have any experience with 3D printing?
   a. Yes
   b. No

4. Are you aware that Winthrop has 3D printing facilities available on campus?
   a. Yes
   b. No

5. How confident are you with using 3D printing?
   a. Very confident
   b. Confident
   c. Neither confident nor unconfident
   d. Unconfident
   e. Very unconfident

6. How confident are you with using technology in general?
   a. Very confident
   b. Confident
   c. Neither confident nor unconfident
   d. Unconfident
   e. Very unconfident

7. How interested are you in using 3D printing?
   a. Very interested
   b. Interested
   c. Neither interested nor uninterested
   d. Uninterested
   e. Very uninterested

8. How interested are you in using technology in general?
   a. Very interested
   b. Interested
   c. Neither interested nor uninterested
   d. Uninterested
   e. Very uninterested

9. Please describe your attitude towards 3D printing.

Demographic Information

1. What is your current age?

2. What is your sex?
   a. Male
   b. Female
   c. Prefer to self-describe:____________
   d. Prefer not to answer

3. Please select all racial and ethnic groups with which you identify.
   a. American Indian or Alaska Native
   b. Hispanic, Latino, or Spanish origin
   c. White
   d. Asian
   e. Middle Eastern or North African
   f. Black or African American
   g. Native Hawaiian or Other Pacific Islander
   h. Another race or ethnicity not listed above, please specify:
   i. Prefer not to answer

4. What is your current overall GPA at Winthrop?
   a. 3.5-4.0
   b. 3.0-3.49
   c. 2.5-2.99
   d. 2.0-2.49
   e. Below 2.0
   f. Prefer not to answer
   g. Unsure

APPENDIX B: QUALTRICS POST-SURVEY

PLEASE ANSWER THE FOLLOWING QUESTIONS.

1. Student Code (as provided by the instructor):_____________

2. Which course did you take?
   a. Molecular Biology
   b. Anatomy and Physiology
   c. Cell Biology

3. Did you have any experience with 3D printing before this course?
   a. Yes
   b. No

4. Were you aware that Winthrop has 3D printing facilities available on campus before this course?
   a. Yes
   b. No

5. How confident are you with using 3D printing?
   a. Very confident
   b. Confident
   c. Neither confident nor unconfident
   d. Unconfident
   e. Very unconfident

6. How confident are you with using technology in general?
   a. Very confident
   b. Confident
   c. Neither confident nor unconfident
   d. Unconfident
   e. Very unconfident

7. How interested are you in using 3D printing?
   a. Very interested
   b. Interested
   c. Neither interested nor uninterested
   d. Uninterested
   e. Very uninterested

8. How interested are you in using technology in general?
   a. Very interested
   b. Interested
   c. Neither interested nor uninterested
   d. Uninterested
   e. Very uninterested

9. Please describe your attitude towards 3D printing.

PLEASE SELECT ONE OF THE FOLLOWING FOR EACH ITEM BELOW.

1	2	3	4	5
STRONGLY DISAGREE	**DISAGREE**	**NEITHER AGREE NOR DISAGREE**	**AGREE**	**STRONGLY AGREE**

Ease of use/usefulness

2. The 3D printer was easy to use.
5. Using current technology, like 3D printing, will benefit me in my future career or educational goals.

Learning value

1. The 3D printed model helped me better understand course concepts.
3. The 3D printed model did not improve my learning experience.*
6. It was easier to visualize abstract course concepts using the 3D printed model.
8. The 3D printed model helped me better understand student presentations.
9. I learn better when a 3D printed model is available.
10. The 3D printing assignment added value to this course

Desire to have 3D technology in more courses

4. I would like more courses to incorporate 3D printing.

How challenging

7. The 3D printing process was challenging.

** Reverse-scored items*

DEMOGRPAHIC INFORMATION

1. What is your current age?

2. What is your sex?
   a. Male
   b. Female
   c. Prefer to self-describe:_________________
   d. Prefer not to answer

3. Please select all racial and ethnic groups with which you identify.
   a. American Indian or Alaska Native
   b. Hispanic, Latino, or Spanish origin
   c. White
   d. Asian
   e. Middle Eastern or North African
   f. Black or African American
   g. Native Hawaiian or Other Pacific Islander
   h. Another race or ethnicity not listed above, please specify:
   i. Prefer not to answer

4. What is your current overall GPA at Winthrop?
   a. 3.5-4.0
   b. 3.0-3.49
   c. 2.5-2.99
   d. 2.0-2.49
   e. Below 2.0
   f. Prefer not to answer
   g. Unsure

5. What is your current grade in this course?
    a. 90-100
    b. 80-89
    c. 70-79
    d. 60-69
    e. Below 60
    f. Prefer not to answer
    g. Unsure

APPENDIX C: ANATOMY AND PHYSIOLOGY PROJECT DESCRIPTION AND GRADING RUBRIC

PROJECT OVERVIEW

Students will work in groups of 4, selected by the instructor. Each group will select an organ to be 3D printed and that organ will serve as the foundation for an oral presentation due at the end of the semester. The purpose of this project is to utilize current technology (3D printing), apply it to anatomical use, connect organs with their systems, and relate this to a clinical disorder. Students will also improve technical communication skills through an oral presentation and interpersonal skills through group work.

PROJECT DETAILS

1) Students will select an organ covered in BIOL 214 to 3D print using the following website options: www.thingiverse.com, https://www.embodi3d.com, or https://3dprint.nih.gov. Students will edit the design, select printing materials, and ensure correct printing of the organ. Further instructions on 3D printing will be provided.

2) Students will outline how this organ fits into the organ system and connect this with a clinical disorder. For example, the kidney belongs to the urinary system, which is composed of the kidneys, urinary bladder, ureters, and urethra. A detailed description of key anatomical features of the organ will be provided by the students and the 3D printed version will be analyzed to determine accuracy of the printing process. Please note, the 3D printed version may not be completely accurate. Students will not be penalized if this is the case, however, the students should be able to discuss the inaccuracies in their presentation.

3) Students will select a clinical disorder related to this organ and present the key causes, symptoms, diagnosis, and treatment.

4) Students will present their findings to the class in a 10-minute oral presentation. All students are expected to speak during the oral presentation. During this presentation, students must use their 3D printed model as a visual aid to explain their clinical disorder. For example, if students choose to discuss kidney stones, the model could be used to demonstrate the location of the stones and how the kidney is treated to eliminate kidney stones. Students will likely need to supplement the model with other visual aids (for example, bringing in something to represent the kidney stones).

5) Students will evaluate their peer's presentations and provide feedback. Students will also provide feedback on their team member's participation and effort.

GRADING RUBRIC

This project is worth 50 total points and will count as 50 out of the 100 points on the final exam. The 3D printed organ and completed PowerPoint presentation is due on August 2, 2019.

Project Item	0 Points	5 Points	10 Points
3D printed organ	Organ is not turned in.	Organ is turned in, but there are significant errors with printing due to incorrect selection of printing materials.	Organ is turned in and complete.
Oral presentation: organ anatomy	No description of organ anatomy included in oral presentation.	Partial description of organ anatomy in each category or entire categories are missing in oral presentation.	Complete and accurate description of organ anatomy, connection to organ system, and asessment of 3D model accuracy included in oral presentation.
Oral presentation: clinical disorder	No description of clinical disorder included in oral presentation.	Partial description of clinical disorder in each category or entire categories are missing in oral presentation.	Complete description of clinical disorder including key causes, symptoms, diagnosis, and treatment. Accurately relates to selected organ.
Oral presentation: use of 3D model to explain clinical disorder	3D model is not included in oral presentation.	3D model is included in oral presentation, but there are inaccuracies in its use.	3D model is appropriately included in oral presentation and helps clarify the clinical disorder.

Project Item	0 Points	2.5 Points	5 Points
Oral presentation: organization and clarity	Oral presentation is confusing and only one student presents.	Oral presentation is organized, but not all students present or some students present very little.	Oral presentation is well organized and all students present proportionally.
Peer and team evaluations	Student did not complete peer or team evaluations. Student did not participate in project based on feedback from peers and/or team.	Student is missing either peer or team evaluations. Student participation was minimal in project based on feedback from peers and/or team.	Student completed both peer and team evaluations. Student fully participated in project based on feedback from peers and team.

Project Item	Points Received	Total Points Possible
3D printed organ		10
Oral presentation: organ anatomy		10
Oral presentation: clinical disorder		10
Oral presentation: use of 3D model		10
Oral presentation: organization and clarity		5
Peer and team evaluations		5

TOTAL SCORE = ______out of 50.

APPENDIX D: MOLECULAR BIOLOGY PROJECT DESCRIPTION AND GRADING RUBRIC

PROJECT OVERVIEW

The purpose of this project is to learn and utilize current 3D printing technology, apply 3D printing to the study of molecular biology, and use a 3D printed object to help communicate current research in molecular biology. This project ties into the review paper and presentation assignment for this course. You must produce a 3D-printed object that is related to your review paper on current research within the field of molecular biology, and you must effectively incorporate the object into your presentation.

PROJECT DETAILS

1) Students will create or find an object/file related to their review paper to 3D print. The following websites are good resources to start with: www.thingiverse.com, https://3dprint.nih.gov, or https://www.embodi3d.com.
2) Students will edit the design and/or printing parameters as necessary, select printing materials, and ensure correct printing of the organ in collaboration with the Winthrop University Creator Space. Please note, the 3D printed version may not be completely accurate. Students will not be penalized if this is the case; however, students should be able to discuss the inaccuracies in their presentation. Further instructions on the 3D printing process will be provided.
3) During the presentation of the review paper, students will explain how their 3D printed object connects to molecular biology and is relevant to their paper. The object will be used to communicate key elements of the review paper.
4) Students will complete the 3D printing project worksheet.
5) Students will evaluate their peers' presentations and provide feedback.

GRADING RUBRIC FOR 3D PRINTING PROJECT

This project is worth 50 total points. **The 3D printed object is due on the day of the student's presentation.**

10 Point Project Items	0 Points	5 Points	10 Points
3D printed object	Object is not turned in.	Object is turned in, but there are significant errors with printing due to preventable student error.	Object is turned in and complete.
Connection of 3D printed object to molcular biology explained in presentation	Object is not connected to molecular biology.	Connection of object to molecular biology exists but is not well explained.	Connection of object to molecular biology is clear and well explained.
Relevance of 3D printed object to review paper explained in presentation	Object is not relevant to review paper.	Object is relevant to review paper but relevance is not well explained.	Object is relevant to review paper and relevance is clear and well explained.
Oral presentation: Utilization and integration of 3D printed object	Object is not discussed in oral presentation.	Object is utilized and/or integrated ineffectively in presentation.	Object is utilized and integrated effectively in presentation.
5 Point Project Items	**0 points**	**2.5 points**	**5 points**
3D printing project worksheet	Worksheet is not completed.	Worksheet is partially completed or completed poorly.	Worksheet is fully and well completed.
Peer evaluations	Does not meet requirements	Meets most or all requirements	Meets all requirements and is well-delivered

Project Item	Points Received	Total Points Possible
3D printed object		**10**
Connection to molecular biology in presentation		**10**
Connection to review paper in presentation		**10**
Utilization in oral presentation		**10**
Worksheet		**5**
Peer Evaluations		**5**

TOTAL SCORE = ______out of 50.

APPENDIX E: MOLECULAR BIOLOGY 3D PRINTING PROJECT WORKSHEET
Answers must be typed.

1. **Describe how you found/created the file you 3D printed. Include a description of any editing or modifications that were made prior to printing.**
2. **Which printer and material did you use to print your object and why?**
3. **Explain how the printer that you used works.**
4. **What was the cost of printing your object?**
5. **What post-processing was required for your object?**
6. **Explain how your object is related to molecular biology.**
7. **Explain how your object is related to your review paper.**