Examining Changes in High School Teachers' Perceptions of Utilizing 3D Printing to Teach Biomedical Engineering Concepts:

Results from an Integrated STEM Professional Development Experience

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Abstract

Three-dimensional modeling and additive manufacturing technologies (i.e. 3D printing) have and will continue to revolutionize biomedical engineering. However, 3D printing within biomedical engineering contexts remains an area of limited focus within secondary education. Many secondary educators are not well prepared to teach about biomedical 3D printing applications. Hence, this study examined if professional development (PD) had an influence on high school biology, and technology and engineering (T&E) educators' perceptions of teaching 3D printing concepts within biomedical engineering contexts. The PD included presentations from a panel of experts who had utilized 3D printing within biomedical applications at a nearby College of Medicine. The findings revealed a significant difference in the amount of 3D printing instruction that teachers reported providing in their courses prior to the PD, and the amount they planned to implement following the PD. Additional analyses discovered that male teachers reported a significantly greater increase in their perceptions of 3D printing than female teachers, and there was no significant difference between biology and T&E educators' perceptions. This study provides implications for researchers, universities, and P-12 educators. The findings demonstrate that meaningful PD experiences can positively influence P-12 educators' perceptions and plans to integrate emerging biomedical engineering concepts in their courses.

Keywords: Additive manufacturing, biomedical engineering education, integrated STEM education, P-12 engineering education, science education, teacher preparation

Introduction

Three-dimensional (3D) printing has been called one of the most revolutionary and powerful tools in pharmaceutical and biomedical fields (Jamróz et al., 2018). Significant advancements in this technology and its use have been realized over the last several years across a multitude of biomedical applications including the manufacturing of individualized drug dosages, tissue engineering (e.g., wound dressing), disease modeling, production of implants that correspond to patient-specific anatomy and pathology, phantoms for education and surgical planning, and cell-based materials for regenerative medicine. The manufacturing of many of these intricate devices, parts, and materials that have customized architecture and functionalities are either unable to be created through traditional manufacturing methods or are produced less efficiently as 3D printing can offer.

In the field of cardiology, 3D printing has been used for detailed, patient specific pre-surgical planning, occasional procedural simulation, improved communication across medical teams, student education, and family counseling (Anwar et al., 2018). A recent systematic review demonstrated 3D printed models to be accurate representations of even the most complex anatomy with utility demonstrated in clinical and educational domains (Lau & Sun, 2019). Three-dimensional printed models have also been used to aid in the placement and anatomical fitting of total artificial heart and left ventricular assist devices for patients with heart failure (Farooqi et al., 2019). Recently, in vitro hemodynamic studies of pathological flow conditions have been aided using realistic mock circulatory loops consisting of 3D printed models of pathologies such as aortic stenosis and aortic valve insufficiency (Thaker et al., 2019). Most notably, 3D printing has been found to reduce time and cost of medical treatment, improve success rates of surgeries, lead to the development of new surgical procedures, shorten operation times, and decrease complications (Jamróz et al., 2018).

Three-dimensional printing has also been transformational for medical device development. The development of medical devices requires multiple iterations of a product's design before clinical testing begins. Frequent modifications are usually required as a product moves from a sketch to a product ultimately to be used in human clinical care (Yock, 2015). Three-dimensional printing is an efficient way to create prototypes of devices that can be tested and revised without the need for a complex and expensive manufacturing set-up. An example of this process occurred with a rib plating device under development at the Penn State College of Medicine (CoM). Multiple prototypes were printed using in-house 3D printers before the product was moved to final manufacturing and clinical testing. The result was an effective design that was licensed for clinical treatment and ultimately acquired for distribution by Zimmer Biomet as the RibFix Advantage product (Zimmer Biomet, 2021).

As demonstrated in the aforementioned examples, 3D printing within current biomedical applications is a rapidly emerging technology that is helping advance the health and wellbeing of society. With the advancement of this technology will come the creation of new jobs and the demand for new skills needed by those working in various biomedical related fields. To continue advancing these technologies it is critical that we teach secondary level students the skills needed to advance 3D modeling and printing within biomedical applications. A good starting point is introducing more students to biomedical activities and increasing their interest in biomedical related careers. The projected job growth for bioengineers and biomedical engineers is faster than the average for all occupations (U.S. Department of Labor, 2021), but biomedical engineering ranks as the ninth most awarded bachelor's degree among all engineering fields (Roy, 2018). Biomedical engineering is also the second highest engineering field in which females are earning their bachelor's degree. However, among all engineering bachelor's degrees earned per year in the United States, only 22% of graduates are females and only 38.5% are minorities (Roy, 2018). To encourage more students, especially females and minorities, to pursue engineering careers we must start at the secondary education level. This includes the need for more female and minority biomedical engineering teachers to serve as role models for students (Sullivan et al., 2019). We must provide increased biomedical learning opportunities for secondary students and ensure their instructors are properly prepared to teach current biomedical content and practices.

Review of Literature

Biomedical Engineering in Secondary Education

In secondary education, biomedical engineering courses and concepts are often taught by technology and engineering (T&E) educators. However, in a survey of T&E educators within the state where this study was conducted, less than one percent of the teachers reported teaching biomedical engineering topics in their courses (Litowitz et al., 2021). Science educators, especially biology teachers, are also frequently selected to teach biomedical engineering courses and concepts in secondary education. Biomedical engineering directly aligns with national P-12 science and T&E education standards (ITEEA, 2020; NGSS Lead States, 2013), providing support for educators to integrate more biomedical engineering instruction within their courses. However, biomedical engineering requires unique knowledge and expertise which can be intimidating to secondary science and T&E teachers who often lack preparation to teach biomedical engineering concepts in depth. Specifically, when teaching about 3D printing within biomedical contexts, teachers need to have expertise in anatomy, physiology, 3D modeling and design, and additive manufacturing processes (i.e. 3D printing). While science teachers often possess expertise regarding biological topics and T&E educators often have advanced 3D modeling and manufacturing skills, most science and T&E teacher preparation programs do not prepare educators with expertise in both areas. This gap highlights the need for high-quality, interdisciplinary professional development (PD) for secondary science and T&E educators so they can help their students apply 3D printing to solve authentic biomedical challenges.

To help educators teach biomedical engineering concepts, a number of curricular resources have been developed. One of the most popular is Project Lead the Way's (PLTW) biomedical science pathway. Their biomedical science pathway for high school students includes four courses: Principles of Biomedical Science, Human Body Systems, Medical Interventions, and Biomedical Innovation. In the final course students partner with a mentor from a medical center, university, or research institution on an independent project where they design a solution to a biomedical problem they identified. PLTW (PLTW, 2021) aligned these pathway courses with the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013), *Standards for Technological and Engineering Literacy* (STEL) (ITEEA, 2020), and the *National Health Science Standards* (NCHSE, 2019). A number of studies have investigated student learning outcomes resulting from the PLTW biomedical science pathway. Williams (2019) found an upward trend in standardized testing scores of PLTW biomedical science students' compared to the downward trend from their non-PLTW peers. Additionally, teachers reported PLTW students out performed their non-PLTW peers in various categories including written work, lab skills, and problem-solving abilities (Williams, 2019). Karara et al. (2021) modified the PLTW biomedical science course to provide a virtual biomedical learning experience for high school students during the COVID-19 pandemic. Students reported gaining new biomedical science skills, an increased interest in learning about biomedical topics, and an increased interest in pursuing a career in a biomedical science field. Despite these positive student outcomes from the classroom-ready standardized PLTW biomedical science curriculum that is aligned with national standards, the high cost associated with accessing and offering PLTW pathways has presented challenges for some school districts (Stebbins & Goris, 2019; Volk, 2019).

In addition to PLTW, some P-12 school districts have adopted other biomedical engineering curricula or created their own curriculum. Lab-Aids® offers the SEPUP™ biomedical engineering curriculum that features a series of student investigations aligned with NGSS and also integrates literacy strategies (Lab-Aids, 2021). TeachEngineering.org, in collaboration with engineers from the University of Colorado Boulder, has developed a free series of biomedical engineering lessons and activities focused on human body systems. This curriculum is also directly aligned with the NGSS (TeachEngineering.org, 2021). Similarly ASEE's eGFI website provides a series of free standards aligned biomedical engineering design challenges for elementary and secondary level students (eGFI, 2021). Furthermore, Jackson et al.'s (2021) soft robotics research demonstrated implications for teaching students to integrate engineering design and robotics within biomedical engineering contexts. Soft robotics are constructed from highly compliant materials that resemble those found in natural organisms, which provides unique applications for prosthetics and medically assistive technologies (Jackson et al., 2021). An example of the advantage of soft robotics over rigid robotics includes the design of an artificial hand which that can be controlled to securely grip fruits and other soft items without crushing them. Jackson et al. found that the soft robotics unit significantly increased female students' perceptions of engineering and the processes of engineering in comparison to a rigid robotics unit. These are just a few exemplars of standards-aligned biomedical engineering curricula that schools are currently implementing. Pending the teacher's training and areas of expertise, these curricula provide the opportunity for students to integrate 3D printing to fabricate and test out their biomedical engineering design solutions.

3D Printing within Biomedical Contexts

As described in the beginning of this article, 3D printing can be purposefully used to help develop new innovations and improve existing products in biomedical fields. The national P-12 T&E education standards, *Standards for Technological and Engineering Literacy* (STEL), advocate for the meaningful integration of 3D printing within medical and health related contexts (ITEEA, 2020). Creating realistic biomedical engineering design challenges for students to solve by using low-grade desktop 3D printers that are accessible to P-12 schools can be challenging. However, secondary educators have found a number of ways to utilize the 3D printing technology available to them to help students solve authentic biomedical engineering design challenges. An example from the STEL describes how students in a high school biomedical engineering class were tasked with designing a functioning 3D printed arm controlled by fishing line. This prosthetic device was a custom design for a student born with a shortened arm (ITEEA, 2020, p. 113). Similarly, ITEEA also offers the REACH challenge focused on designing assistive technologies. In this international competition students have to design an original device that can help a person with a disability conduct everyday activities. Many of the past award winners have utilized 3D printing to produce their final solutions (ITEEA, 2021). There are also a number of other prosthetic student design challenge initiatives such as the e-NABLE global network aimed at 3D printing free prosthetic hands for underserved populations around the world (e-NABLE, 2021). Most notably is the prosthetic hand designed by students in a Pennsylvania high school. They designed a custom 3D printed hand and various attachments, with all finger movements controlled by Arduino sensors, to allow a disabled student to play various instruments in her school music class (Murray, 2016). Additionally, in some of the curricula mentioned in the previous section, 3D printing could be integrated within various lessons if teachers are prepared to do so. For example, in the PLTW capstone project students can identify a person or animal in need of an assistive device and 3D print their design. While anatomical models and prosthetics are the most common application of biomedical engineering and 3D printing integration in secondary education, there are additional scenarios that can be developed to challenge students to integrate 3D printing within authentic biomedical contexts. The 3D modeling and design skills developed by students during prosthetic design challenges are applicable across many 3D printing contexts.

3D Printing Professional Development

Compared to science educators, T&E educators will likely have more experience with 3D modeling software and 3D printing due to coursework dedicated to these topics in T&E teacher preparation programs (Litowitz, 2014; Litowitz et al., 2021). However many teachers will still need training to apply 3D printing to biomedical contexts, and universities are vital partners for providing the expertise related to this type of training (Novak, 2019). In a broad review of literature related to 3D printing within biological education contexts, Hansen et al. (2020) found very few studies focused on P-12 education and no studies focused on professional development (PD) required for P-12 instructors to incorporate 3D printing in the life sciences. They cited this as an important area for future research. Similarly, Novak (2019) identified 3D printing PD for P-12 teachers as an area "lacking peer-reviewed evidence" (p. 44) and in need of more research. Moreover, Novak's (2019) research revealed an urgent need for universities to offer intensive hands-on PD for P-12 educators because they help to "up-skill teachers, and inspire them to embed the technology into their classroom for the betterment of their students" (p. 45).

Among the limited literature on 3D printing PD in P-12, studies have found that one-day intensive PD experiences offered by universities can improve teachers' knowledge and skills in this area (Asempapa & Love, 2021; Novak, 2019). One-day 3D printing PD sessions for secondary teachers have also been shown to increase inter-school and cross-disciplinary collaborations related to lesson planning (Asempapa & Love, 2021; Novak, 2019). Asempapa and Love (2021) discovered additional cross-disciplinary benefits from a one-day 3D printing PD workshop. They found significant increases in teachers' mathematical modeling knowledge, and 86% of the teachers indicated they were more likely to collaborate with other STEM (science, technology, engineering, and mathematics) teachers and implement 3D printing in their classroom to teach interdisciplinary concepts. Additionally, Novak (2019) found that intensive one-day 3D printing PD workshops increase teachers' understanding and interest in 3D printing. He also discovered that these valuable PD sessions provide opportunities for teachers from different disciplines and schools to collaborate, share new strategies to integrate 3D printing within existing curricula, create more enriching cross-disciplinary lessons and design challenges, and share advice on how to overcome barriers associated with implementing more 3D printing in schools (e.g., access and funding). While not related to teacher PD, our review of the literature discovered one study in which 3D printing enhanced students understanding of chemistry concepts. University students in a foundational chemistry course were taught how to draw and 3D print a molecule of their choice in two short class sessions. Students reported they would like to see increased use of 3D printing within their chemistry courses, and the 3D printed model improved their comprehension of the 3D shape of the molecules (Dickenson et al., 2020). Although there is limited research on 3D printing PD, the aforementioned studies indicate that short intensive trainings can provide numerous benefits for both teachers and students.

Perceptions Among Males and Females. Some studies have also investigated differences among males' and females' perceptions about 3D printing. Numerous barriers have been identified as limiting female students' opportunities, interest, and confidence to engage in STEM lessons, specifically T&E activities such as 3D printing (Sullivan et al., 2019). Furthermore, educators' perceptions have been found to have a significant impact on students' engagement with 3D printing. Cheng et al. (2020) discovered that educators' perceptions regarding the importance of integrating 3D printing within science instruction had a greater influence on female students' motivation to learn about T&E concepts than their male counterparts. Sullivan et al. (2019) recommended introducing female students to STEM and 3D printing at an early age to increase their confidence in these domains. They also found authentic design challenge scenarios that were relevant to female students' interests and experiences helped increase their engagement. Given female students' increased interest in biomedical engineering compared to other engineering fields (Roy, 2018), biomedical design challenge scenarios could help increase females' interests in engineering practices such as 3D printing.

Purpose of the Study

The review of literature suggests that purposefully integrating 3D printing within authentic biomedical contexts should be beneficial for student learning and the future of biomedical engineering. National P-12 science and T&E education standards advocate for these types of meaningful cross-cutting learning experiences, and it is clear that many teachers would benefit from PD on 3D printing within biomedical contexts. However, the review revealed no studies that examined the impact of a cross-disciplinary PD experience focused on 3D printing within biomedical contexts at the secondary education level. This gap in the literature led to the development of the following research questions which guided this study:

Research Question 1 (RQ1) - To what extent did the professional development (PD) experience change educators' perceptions about the use of 3D printing to teach biomedical engineering concepts?

Research Question 1-Sub Question 1: (RQ1-SQ1) – As a result of the PD, was there an identifiable difference between female and male educators' perceptions about using 3D printing to teach biomedical engineering concepts?

Research Question 1-Sub Question 2 (RQ1-SQ2) - As a result of the PD, was there an identifiable difference between biology, and technology and engineering (T&E) educators' perceptions about using 3D printing to teach biomedical engineering concepts?

Research Question 2 (RQ2) - To what extent did the PD experience influence teachers' intent to use 3D printing in their future instruction?

Methodology

Professional Development Experience

The PD experience resulted from a grant awarded by the authors' institution. This grant program specifically sought to support interdisciplinary projects that addressed important needs while also showing potential for future growth. The researchers developed the idea for the PD experience based on feedback from P-12 school districts and teachers across the state. The project focused on providing an interdisciplinary STEM PD experience for high school biology (including anatomy and physiology), and T&E teachers to collaborate and enhance their knowledge about biomedical engineering applications. It also aimed to encourage the integration of more biomedical content within their courses.

The PD opportunity was advertised to schools across the state through STEM educator association websites, state STEM supervisors' newsletters, and the University's STEM outreach institute. To be eligible for the PD, educators had to currently be teaching a high school biology, anatomy, physiology, T&E, or a related STEM class. Educators had to attend in pairs consisting of one science (biology, anatomy, or physiology) teacher and one T&E teacher from the same high school. Teachers who met this criteria were selected based on the order in which they applied, resulting in a cohort of 26 educators from 13 different school districts across the state.

The PD consisted of two sessions offered two weeks apart for a total of 10 hours. Participants received a copy of the presentations and state continuing education credits for attending. Due to COVID-19 restrictions both sessions were offered synchronously online. The PD engaged teachers in presentations and demonstrations from mechanical engineering and biomedical engineering faculty members, a pediatric cardiologist, and the Dean of the Center for Medical Innovation at the Penn State CoM. All had experience with current 3D printing practices used in biomedical applications, especially cardiology related cases. A summary of the content from each of their presentations and demonstrations is described in the subsequent section.

Professional Development Content

One of the authors who is a pediatric cardiologist presented on his experiences using 3D printing at the Penn State CoM. He described how 3D printing is currently utilized to enhance pre-surgical planning for the repair of complex congenital heart defects. Some examples to date include assessing the spatial relationship of septal defects to the outflow tracts of the heart, visualizing the placement of anticipated patch material within the heart, and determining the position and course of complex blood vessels relative to the heart and other landmarks within the chest. Created from pre-operative CT or MRI scans, 3D printed models provide the cardiac team an invaluable way to visualize the anatomy before embarking on a surgical or catheter-based procedure. Occasionally, findings on the 3D printed models influence the procedural strategy, thus allowing for optimal outcomes with potentially reduced morbidity and mortality. Three-dimensional modeling to assess how implantable hardware fits within the chest of a pediatric sized patient is another area of potential clinical applicability. Three-dimensional models of the heart are also used to enhance cardiology education offered to medical students and post-graduate trainees at the Penn State CoM. In addition to the remarkable clinical and educational benefits, 3D printed models have been instrumental in providing meaningful, patient-specific counseling to parents prior to their child undergoing a cardiac procedure. During his presentation, the cardiologist showed examples of echocardiogram, CT, and MRI scans to the teachers. Using pictures as well as his webcam, he also showed teachers a number of 3D prints generated from these images and demonstrated why they were helpful in enhancing clinical care. He also used these to show how much the quality and complexity of the prints advanced in just the past five years.

Another author who is a biomedical engineer and specializes in circulatory support devices presented on the research and development of left ventricular assist devices and artificial hearts at the Penn State CoM. He explained that in the initial development of new device designs, his team uses 3D printed models to assess the positioning and anatomical fit in large animal studies. In addition, his team presents the 3D models to cardiovascular surgeons in order to get clinical feedback during the design iteration process. Additionally, a mechanical engineering faculty member who specializes in thermal therapies and medical device development at Penn State Harrisburg presented on his research and work with undergraduate engineering students' capstone projects that utilized 3D printing in biomedical contexts. He presented on topics such as engineering product development processes and prototyping. The engineering faculty member showed example videos and prototype images of student capstone projects while explaining the biomedical concepts that served as the basis for their innovations. Some examples focused on vascular navigation of therapeutics, prosthetic arms, lower limb protheses, and smart home innovations to address aging in place. These examples were in collaboration with Penn State Harrisburg's Department of Kinesiology and the Penn State CoM. In one specific example students had utilized a microcontroller and sensors to develop a wearable arm band with a 3D printed enclosure to measure and track elderly residents' scapulothoracic motion (Rapp et al., 2017). Another example showcased a 3D printed prosthetic arm controlled by a microprocessor and sensors. The teachers' reactions to this presentation were overwhelmingly positive with all but one participant rating it as excellent on the post survey. They expressed that it helped enhance their understanding of ways in which students will further develop the skills learned in secondary STEM classes to solve complex interdisciplinary problems at the undergraduate level and beyond.

Lastly, one of the authors from the Penn State CoM's Center for Medical Innovation explained what the process might look like when going from concept to a medical device approved for human use. Many teachers related this to the scientific process and engineering design process that they utilize in their classes. The examples presented by the author appeared to be valued by the teachers as some commented that they planned to share these examples with their students. One of the main examples presented was the RibFix Advantage product (Zimmer Biomet, 2021). Teachers were shown pictures and videos of various 3D printed prototypes that were tested to develop the final product.

Instrument

In addition to collecting demographic information, the following five-point Likert scale items were developed by the authors. Face validity of the items was established based on the authors' expertise in integrated STEM education, biomedical engineering, and 3D printing in authentic biomedical applications. These items examined potential changes in participants' perceptions regarding the teaching of 3D printing concepts within biomedical engineering contexts:

Item 1 – Pre- and post-survey: I believe 3D printing should be used to teach biomedical and human body concepts.

Item 2 – Pre-survey: Currently, how much do you teach about 3D printing in your classes?, and Post-survey: In the future, how much do you see yourself teaching about 3D printing in your classes?

The electronic pre-survey was sent via email to participants prior to the start of the first PD session, and the post-survey link was provided to participants at the end of the last PD session. Participants were provided a unique participant number which they submitted in both their pre- and post-survey responses. These numbers were used by the authors to match participants' pre- and post-survey responses to conduct statistical analyses using the SPSS 27 software package.

Participants

Approximately 24 of the 26 participating teachers completed the pre-survey. The post-survey yielded results from 16 participants (62% response rate among the 26 total participants), leading the researchers to remove responses from eight participants who did not complete both the pre- and post-surveys. A potential reason for the lack of post-survey responses may have been the timing of the survey and PD. The PD was conducted in June 2020, at the end of an academic year in which teachers experienced many challenges due to COVID-19. Participants were encouraged to complete the post-survey at the end of the last PD session and were sent two reminder emails. The 62% response rate exceeded the average rate (33%) for online survey responses (Nulty, 2008). To address concerns about attrition bias, Mann-Whitney U tests were conducted (Miller & Wright, 1995) to examine the pre-survey responses between the 16 participants that completed both the pre-and post-survey and the eight participants that elected not to complete the post-survey. When examining the pre-survey responses for Item 1 ($U = 54.5, p = .528$) and Item 2 ($U = 54.0, p = .445$) there was not a significant difference between the two groups, allowing the researchers to rule out concerns about attrition bias.

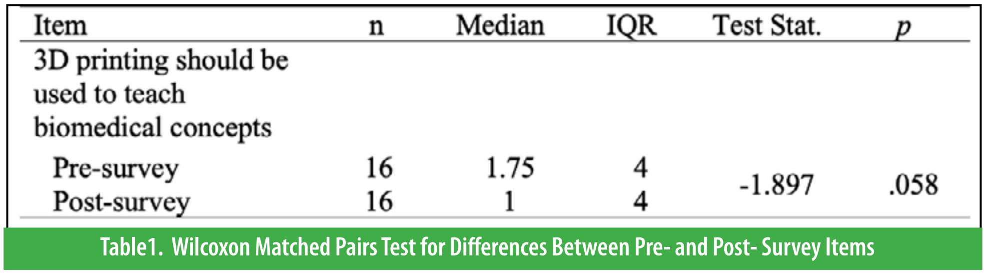
Among the 16 participants, the majority were White (94%) with an even number of males (8) and females (8). The mean age was 41, the average years of teaching experience among the group was 12, and most (75%) held state certification to teach secondary biology courses with the rest (25%) possessing T&E teaching certification. In regard to prior biomedical engineering course work or PD, the majority of participants (63%) reported having limited or some experience while 19% reported no prior course work or PD on this topic.

Findings

Perceptions About Using 3D Printing to Teach Biomedical Engineering Concepts (RQ1)

Using a five-point Likert scale, participants were asked on the pre- and post-surveys to what extent they believed 3D printing should be used to teach biomedical engineering concepts (survey Item 1) . To examine the change between the pre-post responses a Wilcoxon matched pairs test was determined to be best suited for analyzing the two related samples with ordinal data from a non-parametric sample (Sheskin, 2011). Using the G*Power software a sensitivity analysis was conducted to analyze the effect size for a Wilcoxon matched pairs test with a sample size of 16, p value of 0.05, and power of 0.8. This analysis indicated that the Wilcoxon matched pairs test as administered with 16 participants had a moderate effect size (0.77) (Cunningham & McCrum-Gardner, 2007) and was acceptable to use in this study.

The Wilcoxon matched pairs test revealed a p-value of .058, indicating there was not a significant difference between educators' perceptions before and after the PD regarding the extent to which 3D printing should be used to teach biomedical engineering concepts (Table 1). Although the gains were not statistically significant, the analysis revealed a p-value approaching 0.05, therefore additional analyses were conducted (RQ1-SQ1 and RQ1-SQ2) to investigate variables that the review of literature suggested may have an impact on educators' perceptions about teaching 3D printing and biomedical engineering concepts.



Item	n	Median	IQR	Test Stat.	*p*
3D printing should be used to teach biomedical concepts					
Pre-survey	16	1.75	4	-1.897	.058
Post-survey	16	1	4		

Table1. Wilcoxon Matched Pairs Test for Differences Between Pre- and Post- Survey Items

Perceptions About 3D Printing According to Gender (RQ1-SQ1)

The gains from the pre- to post-survey questions used in RQ1 were further analyzed to determine if there was a significant difference between female and male participants' perceptions regarding to what extent 3D printing should be used to teach biomedical engineering concepts. It was determined a Mann-Whitney U test was best suited for analyzing the two independent samples (gender) with an equal or unequal sample size and ordinal data from a non-parametric sample (Sheskin, 2011). The analysis revealed a p-value of .048 indicating there was a significant difference between female and male educators' perceptions. More specifically, male teachers reported a significantly greater increase in their perceptions about using 3D printing to teach biomedical engineering concepts (Table 2).

Perceptions About 3D Printing According to Certification Area (RQ1-SQ2)

Once more the gains from the pre- and post-survey questions used in RQ1 were further examined. This time they were analyzed to determine if there was a significant difference between biology and T&E educators' perceptions regarding to what extent 3D printing should be used to teach biomedical engineering concepts. A Mann-Whitney U test was used to analyze these two independent samples and revealed a p-value of .800. This indicates there was no significant difference between the participating biology and T&E educators' perceptions about using 3D printing to teach biomedical engineering concepts

Intended Use of 3D Printing to Teach Future Biomedical Engineering Lessons (RQ2)

Using survey Item 2, participants were asked to rate how much they currently teach students about 3D printing in their courses (pre-survey) and how much they plan to teach students to use 3D printing in future courses (post-survey). A Wilcoxon matched pairs test was again determined to be best suited for analyzing these two related groups from a non-parametric sample. This analysis revealed a p-value of .002, indicating there was a significant difference between teachers' use of 3D printing in their classes prior to PD, and their plans to integrate 3D printing into their instruction after participating in the PD and seeing the authentic biomedical engineering applications for this evolving technology (Table 4).

Similar to RQ1-SQ1 and RQ1-SQ2, Mann-Whitney U tests were conducted to further examine if there was a statistically significant difference among teachers' intent to integrate 3D printing according to gender or teaching certification area. These analyses revealed no significant differences according to gender ([Females: Mdn = 1, M rank = 9.38; Males: Mdn = 0, M rank = 7.63] U = 25.000, z = −.810, p = .418) and certification area ([Biology: Mdn = 1, M rank = 8.92; T&E: Mdn = 0, M rank = 7.25] U = 19.000, z = −.668, p = .504). This indicates that the PD significantly influenced teachers' plans to integrate 3D printing into their instruction regardless of gender or certification area.

Item	n	Median	Mean Rank	U	Z	*p*
3D printing should be used to teach biomedical concepts						
Females	8	1	10.75	14.000	-1.973	.048*
Males	8	2	6.25			

Note. * p < 0.05

Table 2. Mann-Whitney U Test for Differences Between Female and Male Teachers

Item	n	Median	Mean Rank	U	Z	*p*
3D printing should be used to teach biomedical concepts						
Biology	12	1.5	8.67	22.000	-.253	.800
T&E	4	1.5	8.00			

Note. T&E = technology and engineering

Table 3. Mann-Whitney U Test for Differences Between Content Area

Item	n	Median	IQR	Z	*p*
Integrating 3D printing into their teaching					
Pre-test	16	1	0.75	-3.115	.002*
Post-test	16	3	2		

Note. * p < 0.05

Table 4. Wilcoxon Matched Pairs Test for Differences Among Pre- and Post-Survey Items

Discussion

This study revealed that while there was not a significant difference in the overall groups' perceptions regarding the extent to which 3D printing should be used to teach biomedical engineering concepts, there was a significant difference in perceptions according to participants' gender but not their teaching certification area. Despite no significant difference among the entire groups' perceptions, the mean ratings from the five point Likert scale pre- and post-surveys indicate their perceptions did increase from 3.88 to 4.25 respectively. Wilcoxon matched pairs tests analyze differences between the medians, therefore the mean scores were not part of the statistical analyses in this study. The means are presented here simply to further examine the changes in participants' perceptions that were not found to be statistically significant.

Additional analyses revealed that teachers' perceptions significantly differed according to gender. When examining the differences between pre- and post-survey mean scores reported by males (1.88) and females (0.88), it is apparent that males had a greater increase in their perceptions about using 3D printing to teach biomedical engineering concepts as a result of the PD. These mean differences were not part of the statistical analyses as Mann-Whitney U tests measure differences between the medians. The Mann-Whitney U test found the gains for this item from the pre- to post-surveys to be significantly higher for male teachers. One reason for this may be related to the PD presenters from the Penn State CoM, all of whom were male. The presenters were selected based on their expertise and experience related to biomedical 3D printing applications. While this study did not investigate if the inclusion of female PD presenters could have a significant impact on female educators' perceptions, the literature suggests that female role models/instructors can be influential in increasing females' interest in STEM topics, especially 3D printing (Sullivan et al., 2019).

From the literature it is plausible to expect biology teachers to report greater gains than T&E teachers regarding their perceptions of 3D printing. T&E teacher preparation programs have more coursework focused specifically on 3D modeling software and 3D printing. Additionally, 3D printing more easily aligns with the engineering design focus of T&E standards and courses. The Mann-Whitney U analysis did not find a significant difference between biology and T&E teachers' perceptions of 3D printing within biomedical contexts. However, biology teachers (1.42) did report a higher mean difference from pre- to post-surveys than T&E teachers (1.25). The mean gains and lack of statistical significance among biology and T&E teachers indicate that educators from both content areas benefited from the PD on this topic. Based on the literature and limited number of T&E educators teaching biomedical related courses (Litowitz et al., 2021), T&E teachers may be familiar with 3D printing concepts but not as familiar with how to apply them to authentic biomedical contexts. The gains reported among teachers from both content areas signify that PD on 3D printing within biomedical contexts can be beneficial and can help prepare P-12 teachers to integrate these concepts.

RQ1, RQ1-SQ1, and RQ1-SQ2 revealed positive changes in teachers' perceptions about using 3D printing to teach biomedical concepts. The final research question (RQ2) examined teachers' use or application of 3D printing in the classes they teach. This question specifically examined their instructional use of 3D printing before the PD, and the projected use of it after the PD. There was a statistically significant increase in teachers' intent to integrate 3D printing in their future instruction as a result of the PD. The sample also reported increases between their mean pre-survey (1.56) and post-survey (2.94) ratings on a five point Likert scale. While changes in the groups' *perceptions* about 3D printing did not significantly change, their *intent* to implement 3D printing did ($p = 0.002$). When examining the data more closely the mean scores reveal that teachers' initial perceptions about using 3D printing to teach biomedical engineering concepts were much higher (3.88) than their actual use of 3D printing in their instruction prior to the PD (1.56). When examining the differences in the mean ratings from pre- to post-survey, teachers' intent to integrate 3D printing showed a greater increase (1.38) than their perceptions about 3D printing (0.37). The insignificant increase in educators' perceptions of 3D printing but significant increase in their intent to implement it contradicts foundational work from educational psychology. Bandura's (1997) self-efficacy theory demonstrates how one's perceptions on a topic can influence their confidence, performance, and expected outcomes relative to that topic. Given teachers' significant increase in their intent to integrate 3D printing for enhanced student learning outcomes, it would also be expected to find significant increases in their perceptions regarding the use of 3D printing to teach biomedical contexts. The reason there were not significant increases in perceptions but there were regarding intended implementation is unknown. It could have been due to a number of external variables such as prior exposure to 3D printing in their school district or news stories they read that highlighted this technology. Further analyses are needed to examine this issue.

An interesting finding that emerged from one of the supplemental post-survey questions was all but one teacher (94%) indicated the demonstrations from the mechanical engineering and biomedical engineering faculty members, the pediatric cardiologist, and the Dean of the Center for Medical Innovation were extremely useful. Additionally, as discussed in RQ1, the mean scores from pre- to post-surveys demonstrated gains. However, the statistical analysis from RQ1 did not find significant increases among the groups' perceptions. This led the research team to question if the online format of the PD had an influence on educators' perceptions and survey responses. A number of studies have found no significant difference in the effectiveness of STEM education PD delivered online versus face-to-face (Binmoshen & Abrahams, 2020; Russell et al., 2009). It is unknown if facilitating the PD sessions in this study via a face-to-face format would have yielded significant pre- to post-survey gains for the entire groups' 3D printing perceptions. Due to the teachers' limited prior experiences with 3D printing in biomedical contexts and the complex interdisciplinary nature of this topic, the research team hypothesizes that a face-to-face PD experience involving interactions with the biomedical specialists and their 3D printed models could elicit additional benefits. Additional research is needed to examine this hypothesis.

Limitations

In light of the findings there are a number of limitations that must be considered. The findings represent the self-reported perceptions of 16 teachers from various regions across one state and may not be generalizable beyond the sample. Although the sample appeared to lack ethnic diversity it was consistent with statewide teacher ethnicity data (Fontana & Lapp, 2018). In regard to gender, this study had a more diverse representation than the state average, especially in STEM teaching fields (Fontana & Lapp, 2018; Litowitz et al., 2021). It is also important to note that the PD event was limited to two online sessions over a two week span (10 total PD hours). Furthermore, the survey instrument did not ask participants about their access to a 3D printer in their classroom or school, or if they had sufficient funding for 3D printer filament. While no participants voiced concerns about 3D printer access or funding for materials during the PD or on the post-survey, it cannot be assumed that every teacher had sufficient access and funding to adequately integrate 3D printing opportunities in their courses.

Conclusions

The findings from this study provide positive implications for increasing the perceptions about and implementation of 3D printing within high school science and T&E courses. With the current limited focus on biomedical engineering instruction in P-12 schools, 3D printing provides an engaging and authentic integrated STEM learning experience for all students, especially females. Three-dimensional printing in biomedical applications has advanced rapidly just within the past five years. This study clearly indicates that universities with expertise in this area can have a significant impact on P-12 teachers by providing meaningful PD experiences. Enhancing educators' perceptions and willingness to teach 3D printing concepts within authentic biomedical engineering design challenges can result in P-12 students being better prepared to advance this continually evolving technology. To collaboratively help researchers, universities, and P-12 educators in this endeavor, a number of recommendations are provided in the next section.

Recommendations

For Future Research

As discussed in the previous section, the PD had all male presenters, and male participants reported greater gains than females regarding their perceptions of using 3D printing. Future 3D printing and biomedical engineering PD efforts should seek to include more female presenters and investigate what influence this has on the post-PD outcomes of male and female participants. Despite many teachers indicating on the post-survey supplemental questions that they liked the synchronous online format of the PD due to COVID-19 restrictions, outcomes from future face-to-face PD on this topic should be examined. Given the abstract and complex nature of 3D printing within biomedical contexts, and most teachers' limited experience integrating concepts from these areas, face-to-face PD could provide opportunities to assist teachers more easily during activities and allow them to physically examine the 3D printed examples shared by the presenters. Additionally, this format could enhance learning and collaborative interactions among teachers. A mixed-methods approach would be beneficial in examining the interdisciplinary lessons and design challenges that teachers develop during and after the PD.

While this study and previous research has found intensive one-day PD sessions to be effective for improving teachers' knowledge about 3D printing (Asempapa & Love, 2021; Novak, 2019), follow-up sessions could prove beneficial. As Novak (2019) recommended, the longitudinal effectiveness of intensive one-day 3D printing workshops needs to be further explored; however, he highlighted potential parallels to studies from medical fields that have found intensive one to three day workshops to be highly effective in training staff members. Further research is specifically needed to investigate if teachers' integration of biomedical and 3D printing concepts increases with additional guidance beyond PD sessions. The relationship between teachers' reported gains and the extent to which they integrate biomedical 3D printing concepts in their courses throughout the year should also be studied to examine the longitudinal impact of PD efforts.

For P-12 Biomedical Engineering Outreach

The aforementioned research recommendations lend themselves to overlap with outreach efforts that can be utilized for data collection. Universities and faculty members (especially females and minorities) with expertise related to biomedical 3D printing applications should seek out partnerships with local school districts and their state department for P-12 education. This can provide much needed outreach and PD experiences for supervisors, teachers, students, and parents to enhance their awareness of and interest in biomedical engineering and 3D printing. Providing face-to-face PD experiences either on a university campus or by taking the necessary equipment and materials to local schools could help engage and inspire attendees more than a virtual experience.

Given the current challenges associated with providing PD for P-12 educators, one-day PD events offer a feasible option and have demonstrated many benefits, "the one-day workshop is a tool that may still be undervalued for its ability to rapidly inspire teachers in new technologies, and create long-term relationships between participants, facilitators and institutions" (Novak, 2019, p. 44). However, it could be beneficial to offer additional PD opportunities throughout the year and provide updated instructional resources to keep teachers informed of emerging technologies and developments related to biomedical engineering. Additional biomedical design challenges should also be developed from PD and other interdisciplinary events to help teachers integrate more 3D printing. Moreover, working with P-12 curriculum developers, teachers, and state education departments to develop standards-aligned instructional resources and offer PD about these resources could provide more encouragement for secondary teachers to implement biomedical engineering design challenges. University faculty members from biomedical fields should partner with colleagues in P-12 science and T&E education content areas to advance the teaching, learning, and outreach of biomedical engineering education.

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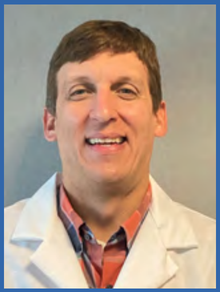

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