Examining Science and Technology/Engineering Educators’ Views of Teaching Biomedical Concepts Through Physical Computing

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Abstract
Programming and automation continue to evolve rapidly and advance the capabilities of science, technology, engineering, and mathematics (STEM) fields. However, physical computing (the integration of programming and interactive physical devices) integrated within biomedical contexts remains an area of limited focus in secondary STEM education programs. As this is an emerging area, many educators may not be well prepared to teach physical computing concepts within authentic biomedical contexts. This shortcoming provided the rationale for this study, to examine if professional development (PD) had a noticeable influence on high school science and technology and engineering (T&E) teachers’ (1) perceptions of teaching biomedical and computational thinking (CT) concepts and (2) plans to integrate physical computing within the context of authentic biomedical engineering challenges. The findings revealed a significant difference in the amount of biomedical and CT concepts that teachers planned to implement as a result of the PD. Using a modified version of the Science Teaching Efficacy Belief Instrument (STEBI-A) Riggs and Enochs in Science Education, 74(6), 625–637 (1990), analyses revealed significant gains in teachers’ self-efficacy toward teaching both biomedical and CT concepts from the PD. Further analyses revealed that teachers reported increases in their perceived knowledge of biomedical and CT concepts and a significant increase in their intent to collaborate with a science or T&E educator outside of their content area. This study provides implications for researchers and educators to integrate more biomedical and physical computing instruction at the secondary education level.

Keywords Biomedical engineering education · Integrated STEM education · Technology and engineering education · Science education · Computer science education · Teacher preparation

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Introduction

National Science and T&E education standards call for biomedical engineering and CT concepts to be taught in PreK-12 curricula. Biomedical concepts can be found within a number of core disciplinary life science and ETS (engineering, technology, and the application of science) standards from the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). They are also embedded in the Standards for Technological and Engineering Literacy (STEL) (International Technology and Engineering Educators Association (ITEEA), 2020), which designate medical and health-related technologies as one of the eight context areas in which students should engage in solving authentic engineering design challenges. Additionally, both the NGSS and STEL call for the integration of CT concepts within a broad spectrum of scientific inquiry and engineering design contexts. CT has been described as a fundamental problem-solving skill that can benefit students in solving abstract problems and understanding human behavior beyond computer science (CS) applications (Weintrop et al., 2016; Wing, 2006). Like biomedical concepts, CT is included as one of the eight science and engineering practices in the NGSS (NGSS Lead States, 2013) (Weintrop et al., 2016) and one of the eight T&E contexts within the STEL (ITEEA, 2020) (Love et al., in press). Furthermore, professional associations such as the National Science Teaching Association (NSTA) and the International Technology and Engineering Educators Association (ITEEA) have advocated for the meaningful integration of CT within STEM content areas (Asante et al., 2021; ITEEA, 2022). The integration of CT within authentic STEM contexts is of great importance due to the need for CT skills within various career fields and the concurrent emphasis placed on greater access to CS for PreK-12 students in the USA. One such field is biomedical engineering, which is rapidly evolving and integrates knowledge of both biomedical science and CT concepts involving electronics, sensors, and microcontrollers (Fuhrmann et al., 2021; Love & Strimel, 2016; Sengupta et al., 2018).

Technological developments in biomedical and CS fields will create new jobs and a demand for relevant skills as those fields evolve. Hence, it is critical to prepare secondary-level students with the skills needed to continue advancing technological and innovative applications of microcontrollers and other computational devices in biomedical contexts. Despite the demand for students to develop these skills and biomedical and CT concepts included in national PreK-12 science and engineering standards documents, the amount of biomedical engineering and CT instruction delivered in secondary schools in the US remains limited (Litowitz et al., 2021; Love et al., 2022a). Ample learning opportunities are needed to immerse secondary students in engaging and innovative biomedical learning experiences that apply CT skills using devices such as microcontrollers to solve authentic engineering challenges. A good starting point is introducing secondary students to authentic biomedical engineering design challenges, which can include programming electronic sensors that adjust to the user based on feedback collected. Thus, secondary science and T&E educators must have adequate preparation to teach these integrative concepts proficiently.

Literature Review

Biomedical Engineering in Secondary Education

Theoretical Premise

Constructivist epistemology postulates that every learner gives information meaning within mental frameworks based on their interactions related to experiences, expectations, and perceptions (Schunk, 2020). These cognitive structures develop with new interactions (Schunk, 2020). The interactions that transpire within an interdisciplinary STEM lesson can benefit student learning by increasing their motivation to learn, fostering innovation, and enhancing their technological literacy (Stohlmann et al., 2012). The NGSS advocates for the situational application of content knowledge in crosscutting contexts (NGSS Lead States, 2013), and engineering design requires the application of crosscutting science, engineering, math, and other concepts to optimize solutions (Margot & Kettler, 2019). Moreover, integrated STEM instruction can enhance students’ problem-solving and critical thinking skills, which are valuable for their future career and academic success (Margot & Kettler, 2019). Thus, teaching biomedical concepts through applied hands-on learning experiences (e.g., engineering design challenges) provides interactions for students to form greater meaning of this information, consequently enhancing their knowledge and application of crosscutting concepts from various domains while also developing valuable lifelong problem-solving skills.

Tactile learning provides experiences in which students can learn by doing, touching, feeling, and engaging in hands-on practices to better process and understand the content (Kanar, 1995). Teaching biomedical engineering concepts through tactile learning has been shown to enhance students’ learning in various contexts. Students studying the anatomy of the human heart using three-dimensional (3D) augmented reality (AR) visualizations scored higher on spatial relations knowledge tests than students who studied two-dimensional (2D) pictures of the
heart (Kruger et al., 2022). Similarly, when students utilized 3D printing to learn anatomical topics, they answered knowledge-based questions with quicker memory recall and more accuracy than students who learned through conventional anatomical teaching methods (Ye et al., 2020). Emerging AR technologies, like augmented reality books (ARBOOK), further highlight the benefits of tactile learning. Students using ARBOOK scored significantly higher on written knowledge tests, attention-motivation, autonomous work, and three-dimensional comprehension tasks than students using traditional 2D book and video methods (Ferrer-Torregrosa et al., 2015). While these tactile learning studies reflect the benefits of constructivist learning strategies in biomedical contexts, qualitative studies have reported a positive increase in students’ perceptions of hands-on learning (Battulga et al., 2012; Brown et al., 2012; Petersson et al., 2009). The literature indicates that tactile learning experiences often help students learn abstract anatomical concepts better than non-tactile methods.

Current Applications in Secondary Schools

A few curricular resources currently exist to guide PreK-12 educators in teaching biomedical engineering concepts. Project lead the way (PLTW) is implemented in many PreK-12 schools nationwide. PLTW offers a biomedical science pathway (PLTW Biomedical Science, 2021) that consists of four courses: Principles of Biomedical Science, Human Body Systems, Medical Interventions, and Biomedical Innovation, all of which have positive alignment with the NGSS (NGSS Lead States, 2013), STEL (ITEEA, 2020), and the National Health Science Standards (NCHSE, 2019). The pathway’s final course includes a project requiring students to identify a biomedical problem and design a solution with a mentor who is a professional in the biomedical field. Numerous studies have reported positive student learning outcomes from the implementation of the PLTW biomedical science pathway. Williams (2019) found that students in PLTW had higher test scores compared to their non-PLTW peers. During the COVID-19 pandemic, Karara et al. (2021) offered a modified PLTW biomedical science course as a virtual learning experience for high school students and reported gains in the students’ biomedical science skills, an increased interest in learning about biomedical topics, and a heightened desire to pursue a career in a biomedical science field. Although PLTW offers a rigorous standards-aligned biomedical engineering pathway that has demonstrated positive student learning outcomes, the classroom-ready curricula offered by PLTW have been criticized for their high cost, which can prohibit PreK-12 schools from offering these courses to students (Love et al., 2022a; Stebbins & Goris, 2019; Volk, 2019).

Some PreK-12 school systems have adopted other biomedical engineering curricula or developed their own. For example, the Lab-Aids® SEPU® biomedical engineering curriculum integrates literacy strategies in a series of student investigations aligned with NGSS (Lab-Aids, 2021). Additionally, TeachEngineering.org and engineers from the University of Colorado Boulder developed a free biomedical engineering curriculum aligned with the NGSS, which features biomedical engineering lessons and activities focused on human body systems (TeachEngineering.org, 2007). The American Society for Engineering Education’s (ASEE) eGFI website presents a free, standards-aligned biomedical engineering design challenge series developed for elementary and secondary level students (eGFI, 2021).

The integration of biomedical engineering concepts within PreK-12 contexts has been exemplified through applications such as soft robotics, characterized by Schmitt et al. (2018) as systems built from materials with mechanical properties similar to those of living tissues, designed and manufactured in a very innovative way rather than artificially assembled by serial or parallel arrangements of elementary blocks, as it was the case for rigid-body robots. (p. 2).

Jackson et al. (2021) explored the integration of a unit on soft robotics and engineering design within biomedical applications in a PreK-12 setting and found a significant increase in female students’ perceptions of engineering and its processes in comparison to a rigid robotics unit. This is one example of many standards-aligned biomedical engineering curricula that schools are currently implementing, which provide students with opportunities to integrate biomedical and engineering concepts as they design and optimize their solutions to solve authentic problems.

Preparation to Teach Biomedical Engineering Concepts

In secondary education, biomedical engineering courses and concepts are often taught by T&E educators. However, in a survey of 277 T&E educators across the state in which the current study was conducted, only one teacher (<1%) reported teaching biotechnology courses which encompass biomedical engineering topics. Conversely, 68% of the teachers in that study reported teaching CS concepts in their T&E courses (Litowitz et al., 2021). This could be a result of the limited science coursework required by T&E teacher preparation programs (Litowitz, 2014) and T&E educators’ limited science content and pedagogical knowledge needed to teach science concepts (e.g., biomedical) in great depth (Love & Hughes, 2022; Love & Wells, 2018). Science educators, especially biology teachers, are also frequently tasked with teaching biomedical science and biomedical engineering courses and concepts. While biology educators usually have a deeper understanding of the science content that is part and parcel of teaching biomedical engineering
Integrating Science Concepts Through Physical Computing in Secondary Education

Access to CS education is critical in PreK-12 schools. A foundational concept of CS is CT, which emerged from Seymour Papert’s (1980) constructionist educational epistemology. Denning et al. (2017) defined CT as “the mental skills that facilitate the design of automated processes” (p. 15). Papert’s constructionism is rooted in constructivist ideology, notably Jean Piaget’s Theory of Cognitive Development and Lev Vygotsky’s Sociocultural Learning Theory (Lodi & Martini, 2021; Papert & Harel, 1991). Constructivism views children as active knowledge builders (Schunk, 2020). Piaget described the schemas children construct with increasing complexity as they progress through discreet stages of development (Schunk, 2020). Vygotsky emphasized the role of social interaction in the continuous reconstruction of the mental frameworks that students develop (Scrimshier & Tudge, 2003). Specific to CT, Papert’s constructionist-based views proposed that learners use the schemas and mental frameworks they develop to transfer understanding of abstract ideas into concrete skills by programming cultural artifacts to model the abstraction (Lodi & Martini, 2021; Papert & Harel, 1991).

Moreover, the mental processes, methods, practices, and transversal skills used to think computationally become more complex as students progress through the secondary grades (Lodi & Martini, 2021). CT helps develop crosscutting problem-solving skills that can benefit all students in solving abstract problems and understanding human behavior (Wing, 2006; Yadav et al., 2014) and lends itself to applications across STEM disciplines (Love et al., in press). Numerous PreK-12 science and T&E education studies have presented methods for integrating CT and STEM. One proposed strategy is physical computing, which teaches students CT skills through hands-on activities that involve programming interactive physical systems or devices via software (Cápay & Klimová, 2019; Genota, 2019). Love and Strimel (2016) and Love et al. (2016) suggested utilizing physical computing to integrate STEM and CT concepts in authentic ways as opposed to teaching standalone coding or CT lessons. There have been many examples of integrating CT with science and engineering practices situated within authentic STEM education challenges. Some of these examples include cardiology (Texas Instruments (TI), 2017a), irrigation systems (TI, 2017b), automated farming (Simpson, 2017), smart greenhouses (Asante et al., 2021), autonomous vehicles and physics concepts (Love & Bhatty, 2019), and elementary literacy and engineering design (Love & Griess, 2020). Furthermore, observations from such applications indicate that students enjoy learning CT concepts when integrated with STEM lessons (Love & Asempapa, in press; Love & Bhatty, 2019; Love & Griess, 2020). The review of the literature indicates potential benefits associated with using physical computing to teach STEM concepts, yet a limited amount of research has documented the benefits of teaching and learning abstract science concepts through tactile physical computing experiences. There is also limited research on PreK-12 engineering and science teacher preparation to deliver integrated science and physical computing instruction.

Teacher Self-Efficacy

Maintaining an optimistic belief in one’s capabilities to complete specific tasks is crucial in exerting control over a task. The concept of self-efficacy was originally conceived by Bandura (1997) and is defined as “beliefs in one’s capabilities to organize and execute the courses of action required to produce given attainments” (p. 3). Researchers have established that teacher efficacy is associated with instructional quality (Holzberger et al., 2013) and positive outcomes in students’ academic achievement (Fauth et al., 2019; Ross, 1992; Tschanne-Moran & Barr, 2004). Based on the concept of self-efficacy, it can be presumed that teachers who believe highly in their students’ ability to learn and who simultaneously have greater confidence in their own teaching skills are likely to have a greater influence on their students’ learning (Gibson & Dembo, 1984). Additionally, research has found a strong positive correlation between teachers’ self-efficacy toward teaching STEM curriculum and students’ STEM academic achievement (Rutherford et al., 2017). Therefore, examining educators’ efficacy toward teaching biomedical concepts through physical computing could provide insight into enhancing students’ biomedical learning experiences.

The Science Teaching Efficacy Belief Instrument (STEBI-A) (Riggs & Enochs, 1990), which has been widely used to investigate teachers’ efficacy, has found professional competence and increased teacher performance to be linked (Savasci-Acikalin, 2014). Agu and Ramsey (2018) demonstrated that the STEBI-A could be modified to examine high school biology teachers’ self-efficacy (effectiveness
of their teaching) and outcome expectancy (influence on their students’ understanding). They found that the modified STEBI-A was both a reliable and valid instrument for measuring teacher efficacy by conducting Cronbach’s alpha and principal component analyses (Agu & Ramsey, 2018). The STEBI-A was also modified by Kaya et al. (2020) to examine educators’ efficacy toward teaching CT concepts. They discovered that introducing CT practices, such as building robots, increased pre-service elementary teachers’ CT self-efficacy (Kaya et al., 2020). The findings from these studies suggest that by applying Bandura’s theory to enhance science and T&E educators’ efficacy toward teaching biomedical and physical computing concepts, one can anticipate greater integration and increased competence in the teaching of these crosscutting concepts.

The literature also indicates that tactile experiences often provide benefits for student learning; therefore, utilizing a hands-on physical computing approach to teach biomedical concepts could enhance students’ knowledge and applications of biomedical engineering. Weintrop et al. (2016) advocated for these types of blended learning experiences in comparison to stand-alone CS instruction because crosscutting experiences can help provide authentic integrative learning experiences. Before student learning can be improved, teachers’ efficacy and expected outcomes for teaching biomedical concepts using engaging tactile methods (e.g., physical computing) must first be enhanced. Past studies have examined teachers’ self-efficacy and expected outcomes toward teaching biological science or CT concepts. There is a need for research examining educators’ self-efficacy and expected outcomes toward teaching biomedical and CT concepts to better understand the influence that tactile CT approaches have on educators’ views toward teaching abstract biomedical concepts.

Enhancing Educators’ Self-Efficacy Through Professional Development

PD experiences that establish content focus, active learning, coherence, sustained location, and collective participation has been found to be effective at improving educators’ pedagogical content knowledge (PCK) and enhancing student learning (Desimone & Garet, 2015). Weintrop et al. (2016) identified a need for PD experiences that increase educator comfort in delivering computation-based instruction that incorporates CT in authentic situations, especially in PreK-12 science and mathematics contexts. Moreover, some teachers have indicated they believe cross-cutting connections are an advantage of STEM education, and PD can provide effective support to improve their STEM integration efforts (Margot & Kettler, 2019). Integrated STEM PD opportunities that encourage collaboration among educators from various technological and scientific areas have demonstrated increases in self-efficacy and expected outcomes toward teaching STEM concepts (Kelley et al., 2020; Love, 2022).

Studies have found that one-day intensive PD experiences offered by universities can improve teachers’ knowledge and skills on integrated STEM topics, increase inter-school collaborations, and increase cross-disciplinary collaborations related to lesson planning (Asempapa & Love, 2021; Novak, 2019). However, there remains limited research focused on biomedical PD experiences for PreK-12 educators. Love et al. (2022a) found crosscutting benefits for PreK-12 T&E and biology teachers during a PD workshop that demonstrated the use of 3D printing in clinical applications to solve biomedical engineering challenges. That workshop, which was facilitated via two online sessions, resulted in significant increases in teachers’ views about integrating 3D printing in their courses and utilizing 3D printing to help students design solutions to biomedical engineering challenges (Love et al., 2022a). The results from these previous PD studies provide a promising outlook regarding PreK-12 teachers’ receptiveness to biomedical-related PD opportunities and the positive benefits PD can have on their interest to collaborate with other STEM educators, their teaching practices, and consequently student learning.

Research Questions

The review of the literature suggests a number of potential benefits for purposefully integrating tactile CT learning experiences, such as physical computing, within authentic biomedical science contexts. National PreK-12 science and T&E education standards advocate for these types of meaningful crosscutting learning experiences, and it is plausible to hypothesize that many teachers would benefit from PD on utilizing physical computing within biomedical science contexts due to their lack of preparation in these areas. However, the review of the literature revealed a limited amount of research has been conducted on cross-cutting PD experiences related to teaching biomedical concepts through tactile CT approaches. This gap in the literature led to the rationale for this study and the development of the following research questions (RQ):

RQ1: What do secondary educators perceive as barriers to implementing more biomedical engineering instruction?

RQ2: To what extent did the integrative PD experience influence educators’ perceived knowledge of biomedical science concepts and perceptions of teaching biomedical science concepts?

RQ3: To what extent did the integrative PD experience influence educators’ perceived knowledge of CT and perceptions of teaching CT concepts?
**RQ4:** To what extent did the integrative PD experience influence educators’ views about integrating biomedical science and CT concepts in their STEM courses?

**RQ5:** To what extent did the integrative PD experience change educators’ views about their collaborative efforts?

### Methodology

#### Professional Development Experience

The PD experience resulted from a grant awarded by the authors’ institution. The researchers developed the idea for the PD experience based on feedback from PreK-12 school districts and teachers across the state. The project focused on providing an interdisciplinary STEM PD experience, requiring school districts to enroll a team consisting of a high school biology teacher (including anatomy and physiology) and a high school T&E teacher to work together. The project attempted to enhance their knowledge about biomedical science and CT applications, foster collaboration, and encourage more biomedical engineering integration within their courses. The PD was held in two online sessions over a two-week span for a total of 10 h. Due to COVID-19 restrictions, both sessions were offered synchronously online, and participants received a set of materials for the PD activities prior to the first session. During the PD, Texas Instruments curriculum specialists modeled how to use physical computing to teach students about the anatomy and function of a human heart while engaging teachers in the four-chambered heart design challenge (TI, 2017a). The specialists showed how to construct the model heart and connect all physical computing components (TI Nspire calculator, innovator hub, wires, and sensors) via a document camera. Additionally, they shared their screen to provide step-by-step explanations on how to program their electronic components in Python, which modeled blood flowing through a human heart. For attending the grant-funded workshop, teachers received state continuing education credits and a classroom set of materials to teach the unit (TI, 2017a) in their school. In addition to learning how to teach this integrative biomedical science and physical computing activity, teachers witnessed 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 College of Medicine.

#### PD Presenters

One of the authors, who is a pediatric cardiologist at the Penn State College of Medicine, showed how tangible models help to enhance pre-surgical planning for the repair of complex congenital heart defects by 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. He explained that tangible models allow for optimal outcomes with potentially reduced morbidity and mortality rates and are used to enhance cardiology education offered to medical students and post-graduate trainees. In addition to the remarkable clinical and educational benefits, tangible 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 tangible heart models to explain the anatomy of the heart and demonstrate why these models are helpful in enhancing clinical care.

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 College of Medicine. He described the process biomedical engineers go through in the initial development of new device designs. Furthermore, he explained that rotary blood pumps must be designed to meet the hemodynamic requirements for patient circulatory support while minimizing hemolysis and thrombogenicity. Computational fluid dynamic (CFD) simulations with realistic blood damage models are used for initial design, followed by in vitro hemolysis testing with prototype devices, and finally, machined pumps are tested in chronic animal models for biocompatibility and thrombogenicity.

Additionally, a mechanical engineering faculty member who specializes in thermal therapies and medical device development at the Penn State Harrisburg presented his research and work with undergraduate engineering students that utilized microcontrollers and microcomputers in biomedical contexts, including CFD simulations, to study drug targeting (Biswas et al., 2019; Moallem et al., 2018). The engineering faculty member showed example videos and images of students’ capstone prototypes while explaining the biomedical science and engineering concepts that served as the basis for the innovations. The examples focused on vascular navigation of magnetic therapeutic carriers using an external magnet, prosthetic arms, lower limb prostheses, and smart home innovations to address aging in place. In one specific example, students utilized a microcontroller and sensors to develop a wearable armband with a 3D-printed enclosure to measure and track elderly residents’ scapulothoracic motion. The sample capstone prototypes demonstrated how CT and biomedical science concepts can be integrated through computational modeling and simulation (Biswas et al., 2019; Moallem et al., 2018), algorithmic development,
and physical computing applications involving Arduino and Raspberry Pi Pico (Sari et al., 2022) with sensors, actuators, and robotics (Ching et al., 2019). On the open-ended post-survey question, teachers expressed that these presentations helped enhance their understanding of ways in which students will further develop the skills learned in secondary STEM classes to solve authentic cross-cutting problems. Lastly, one of the authors from the Penn State College of Medicine’s Center for Medical Innovation explained what the process can 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 their students apply in class.

**Instrument**

For this study, the researchers used the STEBI-A instrument (Riggs & Enochs, 1990). The STEBI-A consists of 25 items measured on a five-point Likert scale to examine two constructs (13 self-efficacy [SE] items and 12 expected outcome [EO] items) related to in-service educators’ teaching of science. The SE items reflect educators’ beliefs about their teaching effectiveness, and the OE items reflect beliefs regarding their teaching having an influence on students’ understanding (Kaya et al., 2020). Riggs and Enochs (1990) found the STEBI-A to have strong internal consistency reliability and construct validity measures for both the SE and EO constructs. Moreover, the STEBI-A has been found to have strong reliability and validity measures when modified for use in biology (Agu & Ramsey, 2018), CS (Kaya et al., 2020), and integrated science and T&E education studies (Love, 2017a, b, 2022; Love et al., 2022b). For this study, minor modifications were made to some of the STEBI-A items to examine participants’ SE and EO related to teaching: (a) biomedical science concepts and (b) CT concepts. To measure biomedical science teaching SE and EO, the term “science” was changed to “biomedical science concepts” in the 25 STEBI-A items. This process was then repeated, but the term “science” was changed to “CT concepts” in the 25 STEBI-A items. This resulted in two modified STEBI instruments (50 items total), one that measured biomedical science teaching SE and EO, and one that measured CT teaching SE and EO. These items were used to examine the effect of the PD and answer the research questions related to these specific topics. The following represent examples of modifications made to item five of the STEBI-A: “I know the necessary steps to teach biomedical science concepts effectively” and “I know the necessary steps to teach CT concepts effectively.” Additionally, a few five-point Likert scale supplemental questions were added to the survey to collect data regarding participant demographics and prior experiences to fully address the research questions.

Due to the slight modifications to the items, the authors conducted Cronbach’s alpha tests to examine the reliability of the instrument items. The pre-survey items had acceptable reliability measures (all SE items, $\alpha=0.895$; all EO items, $\alpha=0.882$). More specifically, the biomedical science SE (pre, $\alpha=0.920$; post, $\alpha=0.917$) and EO items (pre, $\alpha=0.712$; post, $\alpha=0.744$), and CT SE (pre, $\alpha=0.948$; post, $\alpha=0.933$) and EO items (pre, $\alpha=0.753$; post, $\alpha=0.660$) demonstrated acceptable to strong reliability. This indicated the instrument could provide a reliable measure of participants’ beliefs toward teaching biomedical science and CT concepts. The 60-item electronic pre-survey was sent via email to participants prior to the start of the first PD session. Before the first survey question, the following definition of CT was provided for clarity: “computational thinking involves solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science. Computational thinking includes a range of mental tools that reflect the breadth of the field of computer science” (Wing, 2006). The post-survey link was provided at the end of the last PD session. Approval for this research was granted by the authors’ Institutional Research Board. Participants were provided a unique participant number, which allowed the authors to match participants’ pre- and post-surveys to calculate a sum of differences for the SE and EO constructs from both the biomedical science and CT questions. Those sums were then used to conduct statistical analyses using the SPSS 27 software package.

**Participants**

The pre-survey was completed by 24 of the 26 participating teachers. The post-survey yielded results from 16 participants (62% response rate among the 26 total participants), leading the researchers to remove responses from those participants who did not complete both the pre- and post-surveys. Potential reasons for the lack of post-survey responses may have been the length of the 60-question survey and the timing of the 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 if there were significant differences between the pre-survey responses of the 16 participants that completed both the pre-and post-survey (completers) and the eight participants that elected not to complete the post-survey (non-completers). When examining the
pre-survey responses for the biomedical science items, there was no significant difference \((U = 43.5, p = 0.214)\) between the completers (Mdn = 63.5) and non-completers (Mdn = 66.5). Additionally, there was no significant difference \((U = 41.5, p = 0.172)\) between the CT item responses from completers (Mdn = 73.5) and non-completers (Mdn = 67). This process allowed the researchers to rule out concerns of attrition bias (Miller & Wright, 1995) and assume the results to be representative of the population of 24 teachers based on the sample responses (Miller & Smith, 1983; Threeton & Evanoski, 2014).

Participants were mostly White, with an even number of males and females. The mean age among participants was 41; the average years of teaching experience among the group was 12, and most held state certification to teach secondary biology. The majority of participants reported having limited to some prior coursework or PD on biomedical engineering. Additionally, most participants had limited to some prior coursework or PD related to CT (Table 1).

## Data Analysis

To examine changes from pre to post responses, Wilcoxon matched pairs tests were determined to be the most appropriate analysis for two related samples with ordinal data from a nonparametric sample (Sheskin, 2011). A sensitivity analysis was conducted using the G*Power software to examine the effect size of a Wilcoxon matched pairs test with a sample size of 16, \(p\)-value of 0.05, and power of 0.8. This analysis revealed that the Wilcoxon matched pairs test, as conducted with 16 participants, had a moderate effect size (0.77) (Cunningham & McCrum-Gardner, 2007) and was acceptable for use in this study.

## Findings

### Barriers Identified for the Teaching of Biomedical Engineering Concepts (RQ1)

One of the pre-survey supplemental questions asked participants, “What do you believe is the top barrier that prevents more teaching of biomedical engineering concepts in secondary STEM courses?” The participants were provided multiple answer options with an opportunity to also write in an open response. The greatest barrier identified by the teachers was a lack of resources and/or curricula (38%). Lack of flexibility to integrate biomedical engineering concepts in their current curricula was the second greatest barrier identified (38%), followed by a lack of training and PD on how to teach biomedical engineering concepts (19%) (Table 2).

### Changes in Educators’ Self-Efficacy, Expected Outcomes, and Perceived Knowledge of Biomedical Science Concepts (RQ2)

Participants were asked to respond to the STEBI-A items measuring their beliefs about their teaching of biomedical science concepts. A Wilcoxon matched pairs test was used to analyze changes in their views about teaching biomedical science concepts before and after the PD. The analyses revealed a significant change in their self-efficacy \((p = 0.003)\) with a moderate effect size \((r = 0.732)\), but no significant change in their expected outcomes \((p = 0.305)\). Additionally, participants were asked to rate their perceived level of

### Table 1 Participant characteristics

| Characteristic                        | n (%) |
|---------------------------------------|-------|
| Ethnicity                             |       |
| White                                 | 15 (94)|
| Two or more ethnic groups             | 1 (6) |
| Gender                                |       |
| Male                                  | 8 (50) |
| Female                                | 8 (50) |
| Certification                         |       |
| Biology                               | 12 (75)|
| T&E                                   | 4 (25) |
| Biomedical CW or PD                   |       |
| Extensive                              | 3 (19) |
| Limited or some                       | 10 (63)|
| None                                  | 3 (19) |
| CT CW or PD                           |       |
| Extensive                              | 1 (6)  |
| Limited or some                       | 11 (69)|
| None                                  | 4 (25) |

T&E: technology and engineering, CW course work, PD: professional development, CT: computational thinking

### Table 2 Barriers to implementing biomedical engineering instruction in secondary education

| Factor                                           | n (%) |
|--------------------------------------------------|-------|
| Lack of resources/curricula                      | 6 (38) |
| Curriculum flexibility                            | 5 (31) |
| Lack of training/PD                              | 3 (19) |
| Limited student interest/not meeting the prerequisites | 1 (6)  |
| Lack of co-planning time                         | 1 (6)  |

PD: professional development
knowledge about biomedical science concepts on a five-point Likert scale before and after the PD. A Wilcoxon matched pairs test indicated participants reported an increase in their perceived knowledge ($p=0.005$) with a moderate effect size ($r=0.704$) (Table 3).

### Changes in Educators’ Self-Efficacy, Expected Outcomes, and Perceived Knowledge of CT Concepts (RQ3)

Similar to RQ2, the participants responded to the STEBI-A items, and Wilcoxon matched pairs tests were used to examine changes in their views about teaching CT concepts before and after the PD. The tests revealed a significant change in their self-efficacy ($p=0.006$) with a moderate effect size ($r=0.683$) but no significant change in their expected outcomes ($p=0.815$). Additionally, participants were asked to rate their perceived level of knowledge about CT concepts on a five-point Likert scale before and after the PD. A Wilcoxon matched pairs test revealed there was a reported increase in their perceived knowledge of CT concepts ($p<0.001$) with a large effect size ($r=0.846$) (Table 4).

### Changes in Integration of Biomedical Science and CT Concepts (RQ4)

Two supplemental questions on the survey asked participants on a five-point scale to rate the amount of content they currently taught (pre-survey) and the amount of content they planned to teach (post-survey) related to biomedical science and CT concepts. Wilcoxon matched pairs tests revealed participants reported significant increases in the amount of biomedical science ($p=0.003$) and CT concepts ($p=0.003$) they taught prior to the PD and the amount they planned to teach after the PD. The analyses for the biomedical science ($r=0.754$) and CT ($r=0.747$) items each had a moderate effect size (Table 5).

### Changes in Collaborative Efforts (RQ5)

Lastly, participants were asked about the frequency in which they collaborated with a teacher in biology or T&E who was out of their content area (ex. biology collaborating with a T&E educator and vice versa). They rated the

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**Table 3** Wilcoxon matched pairs tests for differences among biomedical science pre- and post-survey items

| Measure                                      | $n$ | Median | IQR | Test stat | $p$   | $r$  |
|----------------------------------------------|-----|--------|-----|-----------|-------|------|
| Self-efficacy                                |     |        |     |           |       |      |
| Pre-survey                                   | 16  | 50.5   | 13  | −2.928    | 0.003*| 0.732|
| Post-survey                                  | 16  | 52.5   | 15.75|          |       |      |
| Expected outcomes                            |     |        |     |           |       |      |
| Pre-survey                                   | 16  | 38.5   | 7   | −1.026    | 0.305 | 0.257|
| Post-survey                                  | 16  | 40     | 5.5 |          |       |      |
| Perceived knowledge of biomedical science concepts |     |        |     |           |       |      |
| Pre-survey                                   | 16  | 3.5    | 2   | −2.818    | 0.005*| 0.704|
| Post-survey                                  | 16  | 4      | 1.75|          |       |      |

$r$ effect size

* statistically significant at the 0.05 level

**Table 4** Wilcoxon matched pairs tests for differences among CT pre- and post-survey items

| Measure                                      | $n$ | Median | IQR | Test stat | $p$  | $r$  |
|----------------------------------------------|-----|--------|-----|-----------|------|------|
| Self-efficacy                                |     |        |     |           |      |      |
| Pre-survey                                   | 16  | 38     | 17.25| −2.733    | 0.006*| 0.683|
| Post-survey                                  | 16  | 43     | 13.75|          |      |      |
| Expected outcomes                            |     |        |     |           |      |      |
| Pre-survey                                   | 16  | 40     | 8   | −0.234    | 0.815 | 0.059|
| Post-survey                                  | 16  | 40     | 4   |          |      |      |
| Perceived knowledge of CT concepts           |     |        |     |           |      |      |
| Pre-survey                                   | 16  | 2      | 1   | −3.384    | <0.001*| 0.846|
| Post-survey                                  | 16  | 3      | 2   |          |      |      |

$r$ effect size

* statistically significant at the 0.05 level
frequency of their collaborative efforts prior to the PD and how much they intended to collaborate with a biology or T&E teacher out of their content area after the PD. The analysis revealed a significant increase ($p = 0.002$) in participants' collaborative efforts prior to the PD and intended efforts after the PD. This analysis had a moderate effect size ($r = 0.774$) (Table 6).

**Discussion**

There are a few limitations of this study that should be acknowledged. The findings represent the self-reported perceptions of a limited number of teachers from various regions across one state and may not be generalizable beyond the sample. Despite the small sample size, the power analysis indicated a moderate effect size for the analyses used. This does not indicate the findings are generalizable beyond the sample, rather it demonstrates the strength of the analyses conducted with respect to the responses reported by the participants. While the sample appeared to lack ethnic diversity, it was reflective of the state’s teacher ethnicity data (Fontana & Lapp, 2018). Regarding gender, this study had more female teachers than the state average for STEM teaching fields (Fontana & Lapp, 2018; Litowitz et al., 2021). It should also be noted that the PD event was limited to two online sessions over a 2-week span, for a total of 10 h.

One contribution of this study to the PreK-12 STEM education literature is the barriers teachers identified as being associated with the lack of biomedical engineering concepts being taught. While not generalizable to all high schools, identifying these barriers may help inform efforts by curriculum developers, administrators, and state departments of education to assist teachers in integrating more biomedical engineering content into their curricula. The findings in RQ1 indicate that teachers’ major concerns lie in curricular issues, specifically lack of flexibility and curricular resources. Weintrop et al. (2016) identified similar barriers but in relation to integrating CT within PreK-12 science curricula. A positive finding from RQ1 was that only one teacher believed limited student interest or academic level was a barrier to integrating more biomedical engineering content. Addressing these barriers to help integrate more biomedical engineering content will be critical for educating and preparing students to pursue careers in biomedical fields and solving the future problems facing society.

The Wilcoxon matched pairs analyses conducted in RQ2, and RQ3 found significant increases in participants’ SE toward teaching biomedical science and CT concepts, but there was no significant change in their EO. Despite no significant difference in participants’ EO, the mean scores from the five-point Likert scale biomedical science (pre = 38.94, post = 40.00) and CT (pre = 39.19, post = 39.81) EO items reveal slight increases were reported. The Wilcoxon matched pairs test analyzes the sample median compared to a hypothetical median; therefore, the mean scores were not part of the statistical analyses conducted. The means are presented here simply to further examine differences between the EO pre- to post-survey responses; however, the Wilcoxon matched pairs tests concluded there was not a statistically significant difference between the EO pre- and post-survey items.

Potential reasons for a significant increase in educators’ SE but not in their EO is explained by Riggs and Enochs (1990).
They described how a teacher may score high in the SE construct because they believe they can teach the concepts, but if they score low in the EO construct, this could reflect beliefs that their students cannot learn even when provided with effective teaching (Riggs & Enochs, 1990, p. 627). They further explained that “Low outcome expectancy paired with high self-efficacy might cause individuals to temporarily intensify their efforts, but will eventually lead to frustration” (Riggs and Enochs p. 626). Related to this study, the significant increase in teachers’ beliefs about their own teaching (SE) but not the outcomes expected from their students (EO) may be related to some of the barriers identified in RQ1 (e.g., lack of resources to teach complex biomedical engineering concepts). Their low EO gains may also reflect a sense of feeling overwhelmed by the amount of new biomedical science and CT applications they learned in a short period of time and the unknown expectations of how their students will perform based on their limited experience teaching these concepts (82 and 94% had limited to no prior training or experience related to teaching biomedical science and CT concepts, respectively). After the participants teach the four-chambered heart activity (TI, 2017a) and other biomedical engineering and physical computing lessons to students, their EO ratings may increase significantly. Their low EO ratings may be reflective of the challenges they encountered during the PD activity. The struggles they experienced, which are often associated with troubleshooting physical computing activities (Love & Asempapa, in press), may have created doubts about how their students might respond to this lesson and how well they as instructors would be able to scaffold students when challenges arise. Further research is needed to examine if participants’ EO ratings changed significantly after they had experience implementing this activity (or other biomedical engineering and physical computing lessons) with students.

The participants’ lack of training and experience related to teaching biomedical engineering and physical computing lessons may have also contributed to the significant increases in their perceived knowledge of content reported in RQ2 and RQ3. It is important to highlight that these were single items on the pre- and post-survey and not a series of content-related questions. While these items did not measure the accuracy or retention of content learned, they do reflect changes in participants’ perceived opinions of their knowledge and preparedness to teach future lessons covering biomedical science and physical computing topics.

Similar to the reported increases in self-efficacy and perceived knowledge of content, teachers may have experienced significant gains regarding their intent to integrate more biomedical science and CT concepts (RQ4) due to their lack of prior knowledge and experience with teaching these concepts. In this way, the PD helped increase teachers’ views about the importance of biomedical engineering from the physical computing activity and expert presentations that demonstrated authentic integrative applications. Additionally, teachers reported a significant increase in their intent to collaborate with science or T&E educators outside of their content area to teach future biomedical engineering lessons. Given the siloed structure of secondary education, collaborative planning time is often limited (Kelley et al., 2020). Consistent with previous research, quality PD opportunities can increase teachers’ views about collaborating with other STEM teachers outside of their content area (Asempapa & Love, 2021; Kelley et al., 2020; Love & Hughes, 2022). The criteria for this PD opportunity, which required teachers to work as a team consisting of biology and a T&E teacher from their school district, was intentionally designed to provide a unique collaborative PD experience that teachers may not receive during the PD events organized by their school district. Other purposefully planned collaborative PD opportunities like the one examined in this study have been shown to increase teachers’ knowledge of content and self-efficacy toward teaching various STEM topics (Asempapa & Love, 2021; Kelley et al., 2020; Love et al., 2022a).

Conclusions

The findings from this study provide positive implications for increasing the integration of biomedical science and CT concepts within high school science and engineering courses. More specifically, this study indicates that utilizing tactile learning strategies such as physical computing can help to teach abstract biomedical science and CT concepts. Integrated PD opportunities like the one examined in this study are essential for training STEM educators to teach more biomedical science and CT concepts in their courses to better prepare students with the knowledge and skills needed to solve authentic problems. This study indicates that quality PD can increase teachers’ beliefs toward teaching biomedical science and CT concepts and may help teachers overcome some of the barriers that limit the integration of biomedical and CT concepts in their courses. It also highlights the importance of partnerships between higher education institutions (including Colleges of Medicine) and PreK-12 school systems to provide relevant and engaging STEM instructional opportunities to enhance students’ problem-solving skills.

Recommendations

While the sample size in this study is small, it provides valuable insight for future research and outreach related to biomedical engineering and physical computing. Future studies should seek to examine the identified barriers from a larger sample of PreK-12 T&E and science educators. Additionally, the influence that physical computing has on educators’ and students’ views toward biomedical science applications...
should be further examined with a larger sample (e.g., the extent to which physical computing increases or decreases the integration of these concepts; its effect on students’ interest and learning of biomedical science topics). The impact on student learning from teachers attending collaborative PD experiences like this should also be examined.

While the results of this study revealed positive gains in participants’ views toward biomedical science, CT, and collaborative opportunities, the impact of hosting the PD fully online versus face to face is unknown. When possible, future biomedical engineering and physical computing PD opportunities should be offered in person so that educators can interact with the tangible models presented by experts and receive additional assistance with the troubleshooting associated with physical computing activities. Future research should examine if the format of PD opportunities has an influence on participants’ knowledge and views toward biomedical engineering and physical computing. Given the complex nature of teaching biomedical science concepts within the context of physical computing and most teachers’ limited experience integrating these areas, face-to-face PD could provide greater opportunities to assist teachers and potentially increase their confidence in teaching similar activities. Additionally, a face-to-face format could provide greater opportunities for collaborative interactions among teachers.

Previous research has found intensive 1-day PD sessions can be effective for improving teachers’ knowledge about STEM topics and increasing their views about collaboration (Asemppapa & Love, 2021; Love et al., 2022a; Novak, 2019). As Novak (2019) highlighted, “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” (p. 44). However, follow-up sessions should be provided to examine the longitudinal effectiveness of intensive one-day biomedical engineering and physical computing PD. Future studies should investigate if teachers’ integration of biomedical science and CT concepts increases with additional guidance beyond short, intensive PD sessions. Lastly, higher education institutions with faculty who have expertise in biomedical engineering and CT applications should work closely with PreK-12 curriculum developers, teachers, and state departments of education to inform the development of standards-aligned instructional resources and offer outreach opportunities (e.g., PD) which may enhance the teaching of these concepts in PreK-12.

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Data Availability All data generated or analyzed during this study are included in this published article.

Materials Availability All data generated or analyzed during this study are included in this published article.

Code Availability All data generated or analyzed during this study are included in this published article.

Declarations

Ethics Approval Research on human subjects has been approved by the Office for Research Protections at The Pennsylvania State University. All participants provided informed consent for participation in this study. No sufficiently identifiable information about participants was included in this manuscript.

Consent to Participate Informed consent of all participants was obtained in compliance with criteria from the Office for Research Protections at the Pennsylvania State University.

Competing Interests The authors declare no competing interests.

References

Agu, P., & Ramsey, J. (2018). A validation of science teaching efficacy belief instrument for biology teachers. Journal of Education and Social Policy, 5(4), 146–157. https://doi.org/10.30845/jesp.v5n4p18

Asante, C. K., Semerjian, A., Xu, P., Jackson, D., Cheng, Y., Chasen, A., Shah, A., Brett, J., & Broadstone, M. (2021). An integrated STEM and computing curriculum for the human-technology frontier. Connected Science Learning, 3(2). https://www.nsta.org/connected-science-learning/connected-science-learning-march-april-2021-integrated-stem-and

Asemppapa, R. S., & Love, T. S. (2021). Teaching math modeling through 3D-printing: Examining the influence of an integrative professional development. School Science and Mathematics, 121(2), 85–95. https://doi.org/10.1111/ssm.12448

Bandura, A. (1997). Self-efficacy: The exercise of control. Freeman.

Battulga, B., Konishi, T., Tamura, Y., & Moriguchi, H. (2012). The effectiveness of an interactive 3-dimensional computer graphics model for medical education. Interactive Journal of Medical Research, 1(2), e2.1–12. https://doi.org/10.2196/ijmr.2172

Bell, T. P. (2012). A letter from ITEEA’s president. Technology and Engineering Teacher, 71(5), 19.

Biswas, G., Hutchins, N., Lédeczi, Á., Grover, S., & Basu, S. (2019). Integrating computational modeling in K-12 STEM classrooms. Proceedings of the 50th ACM Technical Symposium on Computer Science Education, 1288–1288. https://doi.org/10.1145/3287324.3293757

Brown, P. M., Hamilton, N. M., & Denison, A. R. (2012). A novel 3D stereoscopic anatomy tutorial. The Clinical Teacher, 9(1), 50–53. https://doi.org/10.1111/j.1743-498X.2011.00488.x

Buchanan, W. W. (2013, February 4). Letter from Walter Buchanan to achieve. American Society for Engineering Education. http://www.asee.org/Walter_Buchanan_to_Achieve_re_NGSS_2-4-2013.pdf

Cápay, M., & Klimová, N. (2019). Engage your students via physical computing! Proceedings of the Annual IEEE Global Engineering
Education Conference, Dubai, UAE, pp. 1216–1223. https://doi.org/10.1109/EDUCON.2019.8725101
Ching, Y., Yang, D., Wang, S., Baek, Y., Swanson, S., & Chittoori, B. (2019). Elementary school student development of STEM attitudes and perceived learning in a STEM integrated robotics curriculum. TechTrends, 63(5), 590–601. https://doi.org/10.1007/s11528-019-00388-0
Cunningham, J. B., & McCrum-Gardner, E. (2007). Power, effect and sample size using GPower: Practical issues for researchers and members of research ethics committees. Evidence Based Midwifery, 3(4), 132–136.
Denning, P. J. (2017). Computational thinking in science. American Scientist, 105(1), 13–17.
Desimone, L. M., & Garet, M. S. (2015). Best practices in teachers’ professional development in the United States. Psychology, Society, & Education, 7(3), 252–263. https://doi.org/10.25115/pse-v7i3.515
cGFU. (2021). For teachers: Biomedical engineering. Retrieved August 22, 2021, from http://teachers_egfi_k12.org/tag/biomedical-engineering/. Published May 21, 2021.
Fauth, B., Decristan, J., Decker, A.-T., Büttner, G., Hardy, I., Klieme, E., & Kunter, M. (2019). The effects of teacher competence on student outcomes in elementary science education: The mediating role of teaching quality. Teaching and Teacher Education, 86, 102882. https://doi.org/10.1016/j.tate.2019.102882
Ferrer-Torregrosa, J., Torralba, J., Jimenez, M. A., Garcia, S., & Barcia, J. M. (2015). ARBOOK: Development and assessment of a tool based on augmented reality for anatomy. Journal of Science Education and Technology, 24, 119–124. https://doi.org/10.1007/s10956-014-9526-4
Fontana, J., & Lapp, D. (2018). New data on teacher diversity in Pennsylvania. Research for Action. Retrieved June 25, 2022, from https://www.researchforaction.org/publications/new-data-on-teacher-diversity-in-pennsylvania/
Fuhrmann, T., Ahmed, D. I., Arikson, L., Wirth, M., Miller, M. L., Li, E., Lam, A., Blikstein, P. & Riedel-Kruse, I. (2021). Scientific inquiry in middle schools by combining computational thinking, wet lab experiments, and liquid handling robots. Proceedings of Interaction Design and Children 2021 (pp. 444–449). ACM. https://doi.org/10.1145/3459990.3465180
Genota, L. (2019, January 23). ‘Physical computing’ connects computer science with hands-on learning. Education Week. https://www.edweek.org/teaching/physical-computing-connects-computer-science-with-hands-on-learning/201901
Gibson, S., & Dembo, M. H. (1984). Teacher efficacy: A construct validated. Journal of Educational Psychology, 76(4), 569–582. https://doi.org/10.1037/0022-0663.76.4.569
Holzberger, D., Philipp, A., & Kunter, M. (2013). How teachers’ self-efficacy is related to instructional quality: A longitudinal analysis. Journal of Educational Psychology, 105(3), 774–786. https://doi.org/10.1037/a0032198
International Technology and Engineering Educators Association (ITEEA). (2020). Standards for technological and engineering literacy: The role of technology and engineering in STEM education. https://www.iteea.org/stel.aspx
International Technology and Engineering Educators Association (ITEEA). (2022). Computational thinking. Retrieved June 25, 2022, from https://www.iteea.org/Resources1507/ComputationalThinking.aspx
Jackson, A., Mentzer, N., & Kramer-Bottiglio, R. (2021). Increasing gender diversity in engineering using Soft Robotics. Journal of Engineering Education, 110(1), 143–160. https://doi.org/10.1002/jee.20378
Kanar, C. (1995). The confident student. Houghton Mifflin.
Karara, A., Nan, A., Goldberg, B., & Shukla, R. (2021). Use of science lab simulation during a two-week virtual biomedical research training summer camp for underserved minority youth: A COVID-19 adjustment. Journal of STEM Outreach, 4(2), 1–15.
Kaya, E., Newley, A., Yesilyurt, E., & Deniz, H. (2020). Measuring computational thinking teaching efficacy beliefs of preservice elementary teachers. Journal of College Science Teaching, 49(6), 55–64.
Kelley, T. R., Knowles, J. G., Holland, J. D., & Han, J. (2020). Increasing high school teachers self-efficacy for integrated STEM instruction through a collaborative community of practice. International Journal of STEM Education, 7(14), 1–13. https://doi.org/10.1186/s40594-020-00211-w
Krüger, J. M., Palzer, K., & Bodemer, D. (2022). Learning with augmented reality: Impact of dimensionality and spatial abilities. Computers and Education Open, 3, 100065. https://doi.org/10.1016/j.caeco.2021.100065
Lab-Aids. (2021). Biomedical engineering: Designed for the NGSS. Retrieved August 22, 2021, from https://www.lab-aids.com/biomedical-engineering
Litowitz, L. S. (2014). A curricular analysis of undergraduate technology & engineering teacher preparation programs in the United States. Journal of Technology Education, 25(2), 73–84.
Litowitz, L. S., Painter, D., & Kaskel, J. (2021). Comprehensive survey of technology & engineering education in PA. Technology and Engineering Education Association of Pennsylvania Journal, 68(4), 5–10.
Lodi, M., & Martini, S. (2021). Computational thinking, between Pappert and Wing. Science & Education, 30, 883–908. https://doi.org/10.1007/s11191-021-00202-5
Love, T. S. (2017a). Perceptions of teaching safer engineering practices: Comparing the influence of professional development delivered by technology and engineering, and science educators. Science Educator, 26(1), 21–31.
Love, T. S. (2017b, July). Tools and materials in primary education: Examining differences among male and female teachers’ safety self-efficacy. In L. Litowitz, & S. Warner (Eds.), Technology and engineering education – Fostering the creativity of youth around the globe. Proceedings of the 54th pupil’s attitude toward technology conference. Philadelphia, PA: Millersville University. Retrieved from https://www.iteea.org/File.aspx?id=115739&kv=21df7a
Love, T. S. (2022). Examining the influence that professional development has on educators’ perceptions of integrated STEM safety in makerspaces. Journal of Science Education and Technology, 31(3), 289–302. https://doi.org/10.1007/s10956-022-09955-2
Love, T. S., & Asempapa, R. S. (in press). A screen-based or physical computing unit? Examining secondary students’ attitudes toward coding. International Journal of Child-Computer Interaction.
Love, T. S., Attalah, A., Tunks, R. D., Cyak, Y., & Harter, K. (2022a). Examining changes in high school teachers’ perceptions of utilizing 3D printing to teach biomedical engineering concepts: Results from an integrated STEM professional development experience. Journal of STEM Education: Innovations and Research, 23(2), 30–38.
Love, T. S., Bartholomew, S. R., & Yauney, J. (in press). Examining changes in teachers’ beliefs toward integrating computational thinking to teach literacy and math concepts in grades K-2. Journal for STEM Education Research.
Love, T. S., & Bhatty, A. (2019). The crumble: Integrating computer science through engineering design. Technology and Engineering Teacher, 79(2), 16–22.
Love, T. S., & Griess, C. J. (2020). Rosie revere’s orangutan dilemma: Integrating computational thinking through engineering practices. Science and Children, 58(2), 70–76.
Love, T. S., & Hughes, A. J. (2022). Engineering pedagogical content knowledge: Examining correlations with formal and informal preparation experiences. International Journal of STEM Education, 9(29), 1–20. https://doi.org/10.1186/s40594-022-00345-z
Love, T. S., Roy, K. R., Gill, M., & Harrell, M. (2022b). Examining the influence that safety training format has on educators’ perceptions of safer practices in makerspaces and integrated STEM labs. Journal of Safety Research, 82, 112–123. https://doi.org/10.1016/j.jsr.2022.05.003
Ye, Z., Dun, A., Jiang, H., Nie, C., Zhao, S., Wang, T., & Zhai, J. (2020). The role of 3D printed models in the teaching of human anatomy: A systematic review and meta-analysis. *BMC Medical Education*, 20(1), 335. https://doi.org/10.1186/s12909-020-02242-x

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