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A Physical Computing Professional Development Study: Examining Differences in Male and Female Teachers' Attitudes Toward Computing (Evaluation, Diversity)

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Abstract

Current P-12 science [1] and engineering education [2] standards call for the integration of computational thinking (CT) within authentic, design-based engineering contexts [3-5]. Physical computing has been proposed as a viable option for applying CT concepts through the engineering design process [6-8]. In addition, some studies have found that physical computing design challenges can influence female students' attitudes toward computing and engineering (e.g., e-textile activities have been found to be more engaging to female students). However, there is limited research examining the influence that physical computing professional development (PD) has on U.S. educators, especially regarding differences between male and female teachers. Therefore, this study investigated how male and female teachers' attitudes toward computing differed after participating in a physical computing PD experience.

The Computing Attitude Questionnaire (CAQ) [9] was used to examine the computing attitudes of 37 (13 males and 24 females) grades 4-8 educators. The results revealed that male and female teachers reported significant increases across numerous attitude constructs. Unlike male participants, females reported significant increases in their comfort with physical computing and attitude toward applying physical computing in their classes. However, when comparing the gains reported by males and females, there were no significant differences between the two groups. Supplemental post-survey questions revealed that while most participants indicated they plan to integrate more physical computing concepts within their courses, no significant differences existed between male and female teachers' intentions to integrate such concepts. This study contributes to the limited literature on P-12 physical computing research within the U.S. It has implications for improving physical computing PD efforts offered by higher education institutions and engineering education programs. Moreover, it provides some insight into males' and females' attitudes toward physical computing, which can help inform the planning of future physical computing design challenges and PD opportunities.

Introduction

The United States (U.S.) has seen an increased emphasis on providing computational thinking (CT) learning opportunities for every P-12 student. The increased emphasis is reflected by the inclusion of CT in the *Standards for Technological and Engineering Literacy* (STEL) [2] and the *Next Generation Science Standards* (NGSS) [1]. These standards promote the integration of CT within authentic, design-based engineering and science contexts. While the benefits of integrating CT and engineering practices are clear, there is still much to learn about the methods used to integrate CT within authentic engineering design challenges. One strategy, physical computing (the design, programming, and automation of physical prototypes using sensors, software, and computational thinking skills), has been proposed as a viable option to teach CT concepts while applying the engineering design process [6-8]. Physical computing has been a part of P-12 engineering curricula and instruction in other countries for several years (e.g., England); however, there is a limited amount of research investigating the benefits of physical computing within P-12 engineering contexts in the U.S. [10]. Moreover, there is limited literature on training P-12 teachers in the U.S. to deliver physical computing instruction. Previous studies have indicated that physical computing can be challenging for students and instructors because of the multi-faceted complexities associated with troubleshooting physical computing systems (e.g., electronic components, microcontrollers, sensors, programming language) [5]. Additionally, some studies have found that the context of physical computing design challenges can influence female students' attitudes toward computing and engineering (e.g., e-textile activities can be more engaging to females compared to robotics construction kits and game design activities, which have traditionally been heavily geared toward males [11]). However, limited research examines how male and female teachers view physical computing and the effectiveness of physical computing professional development (PD) efforts. Therefore, this study investigated how male and female teachers' attitudes toward computing differed after participating in a physical computing PD experience.

Literature Review

Benefits and challenges of physical computing for students

Studies have documented several benefits for students resulting from physical computing experiences, including increased student creativity, cognitive load, engagement, motivation, and collaboration [12-15]. When examining differences in how students benefit from physical computing, some studies have discovered that physical computing can result in more significant outcomes for female students than male students. Compared to screen-based activities, physical computing has been found to be more engaging for female students [14,16]. Furthermore, physical computing activities have been found to increase female students' interest in learning to code, their confidence in learning to code [15], reduce their technological anxiety, and increase their intention to use technology in the future [17]. Despite these documented benefits of physical computing for female students, there remains limited research on the benefits of physical computing for female teachers.

Benefits and challenges of physical computing for teachers

Studies examining various topics related to teachers' views of physical computing and their pedagogical strategies are well documented in the literature. Findings from many of these studies reflect results similar to those expressed by students regarding their views and concerns with physical computing. One example is the difficulty in helping a whole class of students develop physical prototypes and assisting with the broad array of troubleshooting issues that arise when working with microcontrollers/sensors and programming software [18-20]. In addition, while studies indicate that educators often believe the concrete hands-on characteristics of physical computing are appealing to teach abstract computing concepts, they also highlight many barriers associated with teaching physical computing [14,20-23]. The barriers associated with teaching physical computing often reiterate the importance of pre-service training and PD on physical computing to better prepare educators for facilitating these complex learning experiences. The importance of training and PD is especially true for elementary educators in the U.S., who often receive limited preparation and PD related to teaching CT, engineering, and physical computing practices [3].

Attitudes and academic achievement

While prior studies have examined various aspects of teaching physical computing and educators' views about physical computing, there remains limited research investigating the differences between male and female teachers pertaining to physical computing. Examining differences between male and female teachers' attitudes toward physical computing provides implications for improving their physical computing instruction, which could then be expected to improve students' achievement related to physical computing [24]. For example, instructor quality has been found to increase students' motivation, improve students' achievement, and influence students' career decisions [24]. Moreover, the literature has suggested that improved efforts to prepare female educators for teaching computing concepts can develop role models that have a more meaningful influence on increasing female students' interest in developing computational thinking, learning computing concepts, and pursuing computing careers [24].

Attitudinal instruments have specifically demonstrated the potential to serve as a reliable predictor of future behaviors related to learning and the amount of effort likely to be exerted [25]. Furthermore, they have been found to have a moderate effect on academic achievement [26]. Therefore, examining how male and female educators' attitudes toward computing change from a physical computing PD provides implications for enhancing physical computing PD experiences and improving physical computing teaching and learning.

Research questions

The following research questions were developed to examine the changes in male and female participants' attitudes toward computing resulting from participation in a physical computing PD experience:

RQ1: To what extent does physical computing PD influence male and female teachers' attitudes toward coding?

RQ2: To what extent do male and female teachers' attitudes toward computing differ after participating in a physical computing PD experience?

RQ3: What influence does a physical computing PD experience have on teachers' intentions to integrate physical computing concepts in their future classes?

Design and Implementation of the Professional Development

Recruitment and selection of participants

The PD was advertised to public school district STEM curriculum coordinators across Pennsylvania through email, a STEM outreach center website from the state's land-grant university, and posts on state STEM education association social media pages. To participate, educators had to attend as a team from their school district, requiring two teachers: (a) an elementary educator teaching in grade four or five and (b) a middle school educator teaching in a STEM-related area. These parameters were intentionally created because the workshop content, materials, and resources were geared toward upper elementary and middle school students. These requirements were also developed in alignment with one of the goals of the PD - to help school districts consider the progression of physical computing learning experiences from elementary through middle school.

Participation was voluntary, and attendees earned continuing education credits from the state education department. There were 40 participants representing 20 distinct public school districts from across the state. Of those 40 participants, 37 educators representing 19 different school districts voluntarily completed the pretest and posttest (93% response rate). The six-hour PD session took place in the spring of 2019. Donor funding obtained by one of the author's universities provided attendees with four Crumble microcontroller starter packs, one of every Crumble sensor found on the Crumble sensor tutorial page [27], and standards-aligned physical computing instructional resources developed by the researchers. The rationale for using the Crumble microcontroller can be found in the Description of the Professional Development section.

Participant demographics

This study involved 37 educators, of which 62% were certified to teach elementary education, and 38% were certified in secondary content areas, of which technology and engineering (T&E) education was the most prevalent. Sixty-five percent of the sample identified as female, and the majority of participants were white (95%). Most participants (87%) had more than five years of teaching experience. Slightly over half (54%) of the participants reported completing a previous PD experience in engineering design, whereas only 38% had previously completed PD in coding/programming. When examining differences between male and female participants, the female participants had a greater percentage (54%) of educators who had been teaching for more than 15 years. In terms of certification, there was a greater percentage of female participants certified in elementary education and a greater percentage of male participants certified to teach secondary T&E (31%) or other areas (e.g., science) (30%). Furthermore, a greater percentage of male participants reported completing prior PD on coding/programming (54%) in comparison to female participants (29%) (Table 1).

Table 1

Participant Demographics

Characteristic	Males n (%)	Females n (%)	Full Sample n (%)
Race			
White	12 (92)	23 (96)	35 (95)
Hispanic/Latinx	1 (8)	0 (0)	1 (3)
Middle Eastern	0 (0)	1 (4)	1 (3)
Years of teaching experience			
1-5 years	2 (15)	3 (13)	5 (14)
6-15 years	7 (54)	8 (33)	15 (41)
>15 years	4 (31)	13 (54)	17 (46)
Certification Area			
Elementary education	5 (39)	18 (75)	23 (62)
Secondary CS	0 (0)	1 (4)	1 (3)
Secondary T&E	4 (31)	3 (13)	7 (19)
Other	4 (30)	2 (8)	6 (16)
Previous PD experience			
Engineering design	8 (62)	12 (50)	20 (54)
Coding/programming	7 (54)	7 (29)	14 (38)

Note. Males n = 13; Females n = 24; Full sample n = 37; CS = Computer science; T&E = Technology and engineering education; PD = Professional development.

Goals and description of the professional development

There were a few goals of the PD: 1) provide teachers with a better understanding of how computational thinking practices are embedded in national and state standards, 2) help teachers gain a better understanding of and comfort with teaching basic CT and engineering design concepts, 3) help teachers identify and plan cross-cutting applications of CT practices by integrating computing concepts with authentic open-ended engineering design challenges (physical computing) to elicit higher order thinking, and 4) provide teachers with the materials and instructional resources to begin implementing physical computing design challenges in their classroom. As previously mentioned, the criteria for eligible participants were intentionally designed to promote the planning of physical computing learning experiences that had a logical progression from the elementary through middle grades.

The researchers purposefully selected the Crumble microcontroller for the PD to meet these goals. Similar to the Micro:Bit, the Crumble is a microcontroller that has been used in England's schools for many years. Previous teacher and student studies have documented success with the Crumble in England and the U.S. due to its durability, affordability, ease of use, wealth of instructional resources available, and appropriateness for students and teachers in the elementary and middle grades who have varying levels of experience with physical computing [5-6,10,28-29]. In addition, the Crumble can be programmed using drag-and-drop block-based coding to control external sensors. Specifically for this project, the Crumble was of interest because it has been shown to have easy compatibility with various low-cost construction materials (cardboard, balsa wood, etc.).

The contents of the sessions were specifically designed to meet the goals of the PD (Table 2). During the first portion of the PD, one of the researchers led a discussion on examples of physical computing systems we interact with in our daily lives and highlighted connections to the national and state standards in science [1], T&E education [2], and computer science [30]. Participants were also shown examples from other countries, like England, which have incorporated physical computing concepts in their primary and secondary national curricula [31]. In the following session, participants were provided a brief overview of fundamental CT processes and engaged in an activity applying those processes to real-life examples. Then participants were introduced to the Crumble and led through an introductory tutorial on controlling a sparkle (the Crumble version of a color-changing LED) with a switch. Participants were then challenged to think about how to add more sparkles and program them to function like a traffic light. The researcher provided individual assistance as needed. During lunch, participants viewed some examples of forthcoming physical computing initiatives from a researcher and retired professor working with researchers from England to develop standards-aligned resources for use in the U.S. [32]. After lunch, the teachers worked with their accompanying educator from their school district to complete a series of sensor tutorials from the Crumble website [27] (Figures 2 and 3). Those who completed the tutorials early were provided the materials and directions for the cardboard buggy design challenge from the Crumble website.

Once teachers better understood core computational thinking concepts and how to program the various Crumble sensors, they were introduced to Rosie Revere's Orangutan Dilemma design challenge [29]. In this design challenge, teachers worked in pairs to develop an enclosure for the orangutans described in the book using basic construction materials (Figure 3). They also had to program some form of an alarm system using the Crumble and sensors to alert the zookeeper when the orangutans escaped the enclosure. Some teachers used reed switches and magnets to create a door alarm, some used a buzzer, and some used a micro switch and light to sensor when the weight of the orangutans left the enclosure [29]. This design challenge was purposefully chosen because it integrated standards-aligned literacy concepts with the physical computing activity, which the researchers believed would be of greater interest for the elementary educator participants who usually have limited training and experience with teaching computing and engineering concepts, and often have limited flexibility to add content that will detract from math and literacy instructional time [3]. This proved to be a great activity to engage the educators from the elementary and middle grades because it included a design activity that could be completed in a reasonable amount of time and involved low-cost materials and tools (Styrofoam, scissors, etc.) that teachers could use with their students or already were using in their classroom. After the educators shared with the group their designs and the challenges they encountered, participants were given about an hour to collaboratively brainstorm and plan physical computing lessons that would align with state standards and their curriculum. Participants were encouraged to work with attendees from other school districts who were teaching at the same grade level and collaborate with the other attending educator from their school district to look at the progression of their lessons from the elementary to middle grades. Teachers were provided with a link to an online folder to share their lesson ideas and instructional resources with the group throughout the year to build a sense of community. At the end of the PD, participants were shown where to find additional resources from the Crumble manufacturer and the researchers. The researcher shared a more advanced collision avoidance design challenge which was appealing to middle school teachers. The collision avoidance design challenge [6] tasked students with designing a miniature car made of low-cost materials. The designed vehicle had to incorporate sparkles, wheel motors, and an ultrasonic distance sensor to prevent it from running into obstacles while displaying the sparkle brake lights when slowing down/stopping. Before the educators left with their kit of Crumbles and sensors, they were asked to complete the posttest.

Table 2

Professional Development Agenda
I. Welcoming remarks and pretest
II. Overview of P-12 computer science, engineering education, and physical computing initiatives a. Computational thinking (CT) and engineering practices in national and state standards b. Examples of physical computing in standards and curricula from other countries c. Discussion on how physical computing can be integrated into existing P-12 curricula in their school district
III. Using the Crumble software: Intro, demonstrations, and beginner activities a. Coding Language Exercise b. Intro to the Crumble software c. Intro to the Crumble components d. Traffic light design challenge e. Extension activity for early completers – Light Matrix Letters
IV. Lunch and guest speaker from the United States/United Kingdom (US/UK) Design, Engineering, and Technology Collaborative Initiative [32]
V. Self-paced tutorials: Programming Crumble sensors a. Micro switch b. Motor c. Ultrasonic Distance Sensor d. Other sensors e. Extension Activity – Cardboard Buggy Design Challenge
VI. Integrative design challenge: Rosie Revere's Orangutan Dilemma design challenge [29]
VII. School lesson/unit collaborative planning time
VIII. Demonstration of additional resources and closing remarks a. Free online instructional resources for the Crumble b. Presentation of the collision avoidance design challenge [6]
IX. Posttest

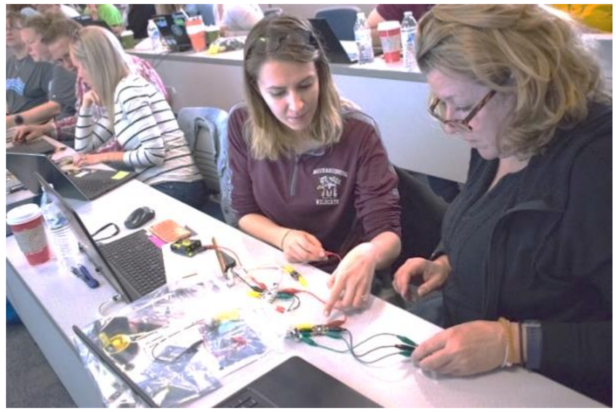

Figure 1

Teachers work to complete a Crumble sensor tutorial with a switch and a sparkle LED (Photo Credit: Penn State Harrisburg, Sharon Siegfried).

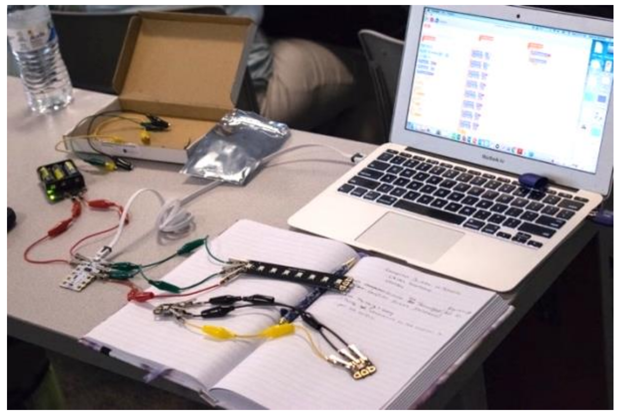

Figure 2

An example of a connected and programmed Crumble circuit involving a switch and a sparkle LED strip (Photo Credit: Penn State Harrisburg, Sharon Siegfried).

Figure 3

Teachers work to construct the enclosure they designed for Rosie Revere's Orangutan Dilemma design challenge [29] (Photo Credit: Penn State Harrisburg, Sharon Siegfried).

Methods

Instrumentation

Yadav et al.'s [9] Computing Attitude Questionnaire (CAQ) instrument was used to examine changes in the participating educators' attitudes toward computing. The CAQ includes 21 Likert scale items (1-5 scale) based on five computing constructs established from Hoegh and Moskal's [33] research. The five constructs of the CAQ include:

- Definition - measures one’s understanding of the definition of computing
- Comfort – measures one’s comfort level with teaching computing concepts
- Interest – measures one’s level of interest in teaching computing
- Classroom applications - measures one’s attitude about integrating computing concepts in their courses
- Career/Future Use - measures one’s attitude regarding the influence they believe computing will have on their students’ future academic and career choices.

Leonard et al. [34] used this instrument to assess changes in the computing attitudes of K-12 educators who received PD on teaching robotics and game design, then taught these concepts throughout the school year. Cronbach’s alpha tests were conducted for this study and revealed high internal reliability for the pretest (0.814) and posttest (0.848) items.

Data analysis

Wilcoxon matched pairs tests were deemed the most appropriate analyses for examining changes between participants’ pretest and posttest responses in RQ1. Wilcoxon matched pairs tests are used to analyze differences between two related samples with ordinal data (e.g., Likert scale) from a nonparametric sample [35]. For RQ2 and RQ3, the Mann-Whitney U analysis was deemed most appropriate for analyzing differences among two independent samples with ordinal data from a nonparametric sample [35]. Additionally, descriptive statistics were presented in RQ3 to further assist in interpreting educators’ responses about the future integration of physical computing in their curricula.

Findings

Research question 1

The first research question examined whether participants’ attitudes toward computing significantly changed from before (pretest) to after (posttest) the PD. Wilcoxon matched pairs tests were conducted separately for males and females according to each computing construct of the CAQ. Additionally, matched pairs rank biserial r correlations were used to calculate the effect size for each Wilcoxon matched pairs group [36]. Both male and female participants reported significant increases ($p < 0.05$) with a large effect size ($r > 0.7$) regarding their attitudes toward the definition of computing and their interest in computing. Moreover, females reported a significant increase with a large effect regarding their attitude toward comfort with computing, and a significant increase with a moderate effect regarding their attitude toward integrating computing concepts in their courses (classroom applications). However, male participants did not report significant attitudinal changes in these constructs. In addition, neither males nor females reported significant changes in their attitudes toward the influence they believed computing would have on their students’ future academic and career choices (Appendix A).

Research question 2

To address RQ2, the researchers conducted Mann-Whitney U tests to examine if there was a significant difference between the changes in male and female participants' computing attitudes according to each CAQ construct. The Mann-Whitney U tests indicated no significant differences between the changes in male and female participants' attitudes in any of the CAQ constructs (Table 3).

Table 3

Mann-Whitney U tests for changes in attitudes toward computing

Construct	n	Median	Mean Rank	U	z	*p*
Definition						
Males	13	1.0	19.31	152.0	-0.129	0.913
Females	24	3.0	18.83			
Comfort						
Males	13	1.0	18.00	143.0	-0.418	0.695
Females	24	2.75	19.54			
Interest						
Males	13	1.0	19.35	151.5	-0.145	0.888
Females	24	2.0	18.81			
Classroom						
Males	13	0.0	17.77	140.0	-0.542	0.626
Females	24	1.75	19.67			
Career						
Males	13	0.0	17.96	142.5	-0.437	0.672
Females	24	2.75	19.56			

Research question 3

The third and final research question examined differences in participants' responses to the four supplemental, fully labeled five-point Likert scale questions on the posttest. The four questions examined participants' views about their likelihood to: 1) integrate computing concepts in their courses, 2) integrate engineering design (ED) concepts in their courses, 3) develop their own physical computing design challenges to use in their courses, and 4) collaborate with a P-12 computer science or engineering educator outside of their content area to implement physical computing in their classroom. The posttest responses were first analyzed according to the full sample (n = 37) using descriptive statistics. Most participants felt somewhat likely or extremely likely to integrate computing concepts (95%) and ED concepts (95%) in their classrooms. More specifically, a greater percentage of participants were extremely likely to integrate ED (65%) compared to computing (51%). In addition, most participants indicated they were somewhat likely or extremely likely (92%) to develop their own design challenges if integrating physical computing in their classroom. Among the four supplemental questions, the likelihood of collaborating with other educators to implement physical computing received the fewest responses in the somewhat likely and extremely likely range (84 %) (Table 4).

Table 4

Descriptive statistics for posttest responses about future integration of physical computing

Response	EU n (%)	SU n (%)	N n (%)	SL n (%)	EL n (%)	μ
Integrate computing	0 (0)	1 (3)	1 (3)	16 (43)	19 (51)	4.43
Integrate ED	0 (0)	1 (3)	1 (3)	11 (30)	24 (65)	4.57
Develop PC DC	0 (0)	2 (5)	1 (3)	16 (43)	18 (49)	4.35
Collaboration	0 (0)	1 (3)	5 (14)	11 (30)	20 (54)	4.35

Note. n = 37; EU = Extremely unlikely; SU = Somewhat unlikely; N = Neither likely nor unlikely; SL = Somewhat likely; 5 = Extremely likely; μ = mean based on five-point Likert scale; ED = Engineering design; PC = Physical computing; DC = Design challenge.

While Table 4 provided a good overview of participants' responses regarding the future integration of physical computing in their classroom, more detailed analyses were conducted to examine these responses according to gender. Mann-Whitney U tests found no significant differences between male and female participants' intent to integrate computing or ED concepts learned from the PD, develop their own physical computing design challenges, or collaborate with other educators to implement physical computing in their classroom. Males reported higher mean ranks for all questions except their intent to develop physical computing design challenges (Table 5).

Table 5

Mann-Whitney U tests for future integration of computing and engineering design

Construct	n	Median	Mean Rank	U	z	*p*
Integrate Computing						
Males	13	5.0	20.54	136.0	-0.718	0.540
Females	24	4.0	18.17			
Integrate ED						
Males	13	5.0	20.92	131.0	-0.950	0.441
Females	24	5.0	17.96			
Develop PC DC						
Males	13	4.0	18.58	150.5	-0.195	0.863
Females	24	4.5	19.23			
Collaboration						
Males	13	5.0	21.27	126.5	-1.040	0.353
Females	24	4.0	17.77			

Note. ED = Engineering design; PC = Physical computing; DC = Design challenge.

Discussion

Limitations

Some limitations must be acknowledged with this study. Although the sample was predominantly White (95%), this mirrors the demographics of teachers in the state where this study was conducted [37]. The survey results were self-reported by teachers who voluntarily enrolled in the PD and consented to complete the surveys. It is unknown if the attending educators had an increased interest in computing, engineering design, and participating in this PD compared to other educators in their school district. Additionally, the supplemental questions were only included in the posttest; therefore, the researchers could not compare pre and post PD changes for these items. Finally, the findings are not generalizable as they represent 37 educators from 19 different school districts in one U.S. state.

Changes in attitudes toward computing

The first research question revealed significant changes in male and female participants' definitions of computing and interest in computing. The demographic findings indicated that only 54% and 29% of males and females respectively had previously completed PD on computing concepts. Participants' definitions of computing prior to the PD may have been narrowly focused on coding and screen-based activities. Integrating engineering design with computing concepts presented through authentic applications in this PD may have broadened participants' perspectives about how computing is defined. The nature of the PD may have also increased participants' interest in computing due to the hands-on nature of physical computing, as previous studies have found [14,20-23]. Positive changes in participants' attitudes toward the definition of computing and their interest in computing align with the goals of the PD.

Interestingly, RQ1 also revealed that, unlike the male participants, females reported significant increases in their comfort with computing and attitude toward integrating computing concepts in their courses (classroom applications). Studies have found that females are more inclined than males to agree that computing is intimidating [24]. The significant increase in comfort among female participants may reflect changes in their views about how intimidating computing can be and the effect of PD. When examining these findings concerning the demographics, it is worth noting that a lower percentage of female participants had previously completed PD on ED (50%) or computing (29%) compared to males. Therefore, unlike male participants, the lower percentage of participating females in PD on ED or computing may have also contributed to their significant increase in comfort with computing.

Furthermore, these previous PD experiences may have also influenced female participants' significant change in attitude toward classroom applications of physical computing. In contrast, males did not report a significant change in this construct. Additionally, many female participants were teaching in the elementary grades (75%) compared to the male participants (39%). Given that secondary grade content areas often have more flexibility to integrate new content in the curriculum in comparison to elementary grades [3], the cross-cutting nature of the design challenge presented [29] within the context of teaching elementary literacy concepts may have significantly changed the classroom application attitudes of female educators (of whom many were teaching at the elementary level). Regarding the last construct, the influence of computing on students' future academic and career choices, there was no significant change in participating educators' attitudes. The lack of participants' attitude change may result from the PD not explicitly incorporating career connections related to the design challenges presented. This mirrors similar findings from the physical computing literature but related to the computing attitudes of middle school students' who participated in a physical computing unit [5]. Love and Asempapa [5] believed that a lack of emphasis on career connections during physical computing instruction impacted students' attitudes toward computing related to their future academic and career choices. Although RQ1 revealed significant increases when examining results specific to males or females, RQ2 found no significant differences when comparing the computing attitudes of males and females.

Future integration of physical computing

The third research question also found no significant differences between male and female teachers' supplemental responses regarding the likelihood that they integrate physical computing into their future instruction. However, when examining the descriptive statistics and mean ranks, females reported higher ratings regarding their intent to develop their own physical computing design challenges to integrate within the curriculum. Given that the majority of female participants were elementary educators (75%), Rosie Revere's Orangutan Dilemma design challenge [29] may have sparked interest in creating design challenges that incorporated a children's book, non-fiction text, or poem related to their current curriculum. Although not statistically significant, the authors view this as a positive outcome aligned with the goals of this PD. This finding suggests an increased interest in physical computing among female educators and in the elementary grades, which often dedicate a limited portion of weekly instructional time to computing [3].

Similarly, males reported higher ratings regarding their intent to collaborate with other teachers to integrate computing concepts in their classrooms. A higher percentage of males were secondary-level teachers (61%) compared to females (25%). The structure of middle schools with teams and team teaching is more conducive to collaboration than elementary schools, where one instructor may be responsible for teaching all content with limited opportunities for collaboration. This finding may explain why male participants reported they were more likely to collaborate with other educators to integrate physical computing instruction. Furthermore, a greater percentage of participants indicated they were extremely likely to integrate ED (65%) compared to computing (51%). This is an interesting result considering that a higher percentage of participants reported completing previous ED PD experiences (54%) compared to computing PD experiences (38%). Participants may have enjoyed the engaging aspect that ED presented for integrating literacy and abstract computing/CT concepts. It is well documented in the literature that students and teachers often find physical computing to present various challenges [18-20]. Participants may have found integrating ED concepts to be more familiar or accessible based on past experiences with this and the complexities encountered when troubleshooting the Crumble microcontroller. They may have been more comfortable working with ED materials (hot glue guns, Styrofoam, etc.) as opposed to the Crumble (e.g., the alligator clips can sometimes be difficult to connect and present issues if they are touching other clips that they should not be in contact with) and abstract computing concepts (e.g., block coding).

Classroom experiences shared by participants after the PD

The researchers contacted participants during the academic year after the PD to see how they integrated physical computing and what additional support they needed. Some teachers confirmed that students, especially in the younger elementary grades, had difficulty connecting the alligator clips and needed assistance. Participants also expressed that students could lose interest quickly if they could not figure out how to follow the tutorial and the instructor could not help them in a reasonable amount of time due to many students needing assistance. An example of one issue was the students struggled with paying attention to details despite instructor directions and the detailed tutorials provided (e.g., the sparkle LEDs have to be connected in one direction or they will not operate, there are arrows on the sparkles to show which direction they need to be connected). One of the researchers witnessed these issues when they were invited by one of the participants to help lead the introductory Crumble tutorial at an elementary STEM open house event. The follow-up conversations with participants also revealed that many teachers found troubleshooting the physical wired/sensor/Crumble connections and programming the Crumble presented challenges when working with a class full of students. They indicated that teacher-led activities tended to work better, but this did not allow for the creativity of student-developed designs. Moreover, teachers expressed that another limitation was the amount of time it took to help younger students become familiar with some of the basic Crumble sensors and functions. They viewed this as a challenge due to their limited flexibility and time to ingrate new concepts into their curriculum. Many participants indicated they used the Crumble for enrichment activities with exceptional students and with after-school STEM clubs because it provided more time to work with smaller groups of students. In these settings, with the capability for increased instructor support, participants reported that students were motivated to troubleshoot their designs and very excited to see what they had programmed and created after their design was finished.

Conclusions

This paper provides data on an area that has been under-researched in the physical computing literature. While many studies have examined student experiences with physical computing and various topics related to teachers' experiences with physical computing, the research on differences between male and female teachers' experiences with physical computing is limited at this time. Although the findings from this study revealed no significant differences between male and female teachers' attitudes toward computing and their intent to integrate physical computing concepts in future lessons, this may be reflective of the limited PD teachers received related to physical computing. As the literature indicates, physical computing has been more prominent in other countries in comparison to the U.S. [10], which recently placed an increased emphasis on computing opportunities for all P-12 students and the integration of design-based STEM practices. The findings are also reflective of the way the PD was purposefully organized. The intentional selection of tutorials (traffic light) and design challenges (Rosie Revere's Orangutan Dilemma [29] and the collision avoidance design challenge [6]) that represented authentic applications which elementary and secondary educators could collaborate on and relate to helped enhance participants' attitudes toward computing regardless of gender. The literature has documented examples of studies specifically focused on investigating strategies to increase female students' interest in physical computing [14-17]. While this study did not aim to increase male or female educators' interest specifically, it did aim to enhance teachers' attitudes about integrating physical computing in their curricula and collaboration with other educators to plan and integrate physical computing design challenges. The findings from this study suggest that well-designed and purposefully planned physical computing PD can positively benefit participants with varying characteristics and background experiences.

Recommendations for Future Physical Computing Professional Development Efforts

A valuable insight gained from this PD experience was the importance of active participation, allowing teachers to experience failure. Hence, they had a better understanding of their students' challenges and how they can best assist them. This PD also demonstrated the importance of modeling rigorous, authentic, integrative design challenges (especially related to physical computing) and engaging teachers in those activities like their students. It was also valuable to highlight the multiple standards that were addressed in the design challenges, helping to change teachers' perspectives from additional content needing to be covered to enhanced learning experiences covering more content than if taught separately.

One of the most valuable aspects of the PD was the collaborative planning time scheduled for teachers to collaborate with other educators from their school district and the same grade level in neighboring school districts. This collaboration time was found to be very beneficial in other integrative STEM PD studies. [4,38]. Future physical computing PD studies should examine differences between elementary and secondary teachers' perceptions of computing while accounting for certifications, content area taught, prior PD experiences, and other characteristics. Additionally, future physical computing PD efforts, design challenges, and curricular resources should include explicit examples of career connections that are related to the physical computing skills being applied. These examples should be carefully selected to ensure they will appeal to a wide range of students regardless of gender, ethnicity, and other characteristics.

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Appendix A

Wilcoxon matched pairs tests for changes in attitudes toward computing

Construct	n	Median	IQR	Test Stat.	*p*	r
Definition						
Males						
Pretest	13	15.0	3.0	-2.427	0.015*	0.818
Posttest	13	17.0	3.5			
Females						
Pretest	24	15.0	2.0	-2.886	0.004*	0.729
Posttest	24	16.0	4.5			
Comfort						
Males						
Pretest	13	25.0	5.5	-1.077	0.282	0.382
Posttest	13	26.0	5.0			
Females						
Pretest	24	24.0	5.0	-3.092	0.002*	0.781
Posttest	24	25.0	3.0			
Interest						
Males						
Pretest	13	17.0	3.0	-2.055	0.040*	0.727
Posttest	13	18.0	4.0			
Females						
Pretest	24	16.0	2.0	-2.890	0.004*	0.766
Posttest	24	17.0	3.0			
Classroom						
Males						
Pretest	13	8.0	2.0	-1.656	0.098	0.800
Posttest	13	9.0	2.0			
Females						
Pretest	24	8.0	0.0	-2.280	0.023*	0.650
Posttest	24	9.0	2.0			
Career						
Males						
Pretest	13	20.0	4.0	-0.416	0.677	0.145
Posttest	13	20.0	3.0			
Females						
Pretest	24	19.0	4.5	-1.463	0.143	0.374
Posttest	24	19.5	4.75			

Note. * = $p < 0.05$