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Teaching Science via Computational Thinking? Enabling Future Science Teachers' Access to Computational Thinking

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Despite the increasing number of coding initiatives to promote computational thinking (CT), their main focus on in-service teachers in large school districts of the big cities far from exemplifies opportunities for preservice teachers (PSTs) to learn how to promote it in rural elementary school settings. As a preliminary step, this research examined how a specific workshop, designed to infuse CT in a science methods course, influenced PSTs' motivation, skill, and usage access to CT. A pre- and post-test quasi-experimental design guided the research. The two intact classroom sections of an elementary education science method course (N=43) were randomly assigned to either a control group or an experimental group. After the covariates were controlled for, attending the workshop increased PSTs skill and usage access as well as their likelihood to incorporate CT in their lesson modifications. PSTs' deeper discussion of CT processes and affordances of CT in relation to the phases of 5E Model is essential to helping them connect CT to the science pedagogy.

As an approach to solving problems by using computer science techniques and methods, computational thinking (CT) has been emphasized as a critical skill necessary for a society that relies on complex computer technologies (Grover & Pea, 2013; Wing, 2008). The growing importance of CT in education has also become clear in the national standards. For instance, computational thinking is included as a one of the core scientific and engineering practices in the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013), while it can also be a thinking process that can support other practices (e.g., developing and using models) and help address the key cross-cutting concepts (e.g., patterns). Such an interest in integrating CT in teaching is due to the increasing computational nature of the science and mathematics fields, which are demanded for current and future workforce (e.g., bioinformatics, computational statistics, or computational neuroscience; Weintrop et al., 2016).

The growing number of educational initiatives (e.g., CS4All) that focus on coding and programming reflects the assertion that such tasks promote CT, as they may provide students with opportunities to explicitly practice CT skills (Voskoglou & Buckey, 2012). However, such efforts tend to target middle and high school in-service teachers in big cities and large school districts (Google Inc. & Gallup Inc., 2016; Guzdial, 2016), while the focus on preservice teachers (PSTs) is limited (Yadav et al., 2017). Consequently, PSTs placed in poorer and rural schools with limited technology access will likely have fewer opportunities to learn how to develop their future students' CT skills.

Thus, equitable CT opportunities in teacher education programs that work with rural placement-schools are essential, and the efforts need to take into account potential digital divide barriers to make CT more accessible to PSTs. As an initial step, the current examined how a specific workshop, designed to infuse CT in a science methods course, may influence PSTs' access to CT.

Further, the skepticism over the limited evidence that CT can transfer to other areas beyond computer science (Denning, 2017; Guzdial, 2015) highlights the potential difficulty that educators may have in relating it to pedagogy. Given the importance of understanding both content and pedagogy in successful use of any technological interventions, the ways in which PSTs' understanding of CT may be connected to their pedagogical approach are also essential to this study. As such, the second aim of the study was to examine the relationship between PSTs' exposure to the CT-infused workshop and their lesson plans designed based on the 5E Model (Bybee, 2015a), a widely accepted inquiry-based instructional model for teaching science conceptual understanding (Contant et al., 2018).

Literature

CT to Problem Solving

CT has been considered as an effective approach that uses computer science concepts and techniques to solve complex problems in a society that relies on complex computer technologies (Wing, 2008). The view that CT can be used to engage students consciously in making artifacts (e.g., design systems) in situated environments reflects the constructionist perspective in education (Papert & Harel, 1991). In particular, CT may start with encountering a problem, breaking it down into smaller components, identifying the patterns among them, abstracting a generic solution, generating algorithms to automate the solution, and analyzing the solution effectiveness (Barr et al., 2011; Grover & Pea, 2013; Wing, 2008), which mirror the problem-solving process, namely understanding and representing, planning, and executing and self-regulation (Mayer & Wittrock, 2006; OECD, 2003, 2015).

Although CT may be broader than just a method to solve problems, such as developing computational models for inquiring and understanding phenomena (Denning, 2017), the problem solving nature of CT has been well recognized and emphasized in the literature (e.g., Voogt et al., 2015). As such, the opportunities that engage students in the CT processes are naturally of interest to educational research and practice focusing on promoting problem solving (Kale et al., 2018). Programming, in the form of developing and executing codes to instruct computers to complete specific tasks, has specifically been viewed as an effective means enabling students to explicitly practice CT skills (Voskoglou & Buckey, 2012). Due to the recursive process of coding, students can have multiple attempts and use multiple problem elements to break down challenging tasks and to develop and test their solutions. As such, coding and programming tasks to promote students' CT may potentially engage students in the problem-solving process.

Coding to Think Computationally

The assertion that programming tasks promote CT is also reflected in the national standards (e.g., NGSS & Common Core), the increasing number of programming classes (Google Inc. & Gallup Inc., 2016), and coding initiatives such as Digital Promise, MakerEd, and CS4All (Herold, 2017; Madda, 2016; Smith, 2016; The White House, 2017). The noticeable surge in research studies on CT also echoes the same trend. According to a recent meta-analysis of empirical papers on CT published between 2006 and 2017 (Hsu et al., 2018), coding and programming was the most focused area. Another meta-analysis focusing on CT assessment also revealed that computing and programming was the most frequently assessed subject (Tang et al., 2020). Further, visual coding programs to promote CT (e.g., block-based programs) have been shown to increase students' self-efficacy toward coding (Arslan & Isbulan, 2021), programming performance (Namli & Aybek, 2022), thinking skills (Gunbatar & Turan, 2019), and academic achievements (Hu et al., 2021).

CT in Teacher Education

Despite the increasing number of coding initiatives to promote CT and the efforts to emphasize critical aspects of CT, their main focus on middle and high school students (Google Inc. & Gallup Inc., 2016) is far from exemplifying opportunities for PSTs to learn how to promote CT in elementary school settings, which may be problematic for the future efforts to support students' CT. Also, while the growing number of new initiatives signals the potential spread of CT to teacher education programs, the majority of the existing efforts still focus on in-service teachers (Yadav et al., 2017).

The growing efforts in teacher education programs, on the other hand, has mostly focused on computer science concepts as a stand-alone subject while a few initiatives emphasize subject-specific CT. For instance, as part of undergraduate educational technology courses, PSTs have been provided with opportunities to practice coding to improve algorithm and debugging skills (Angeli, 2022), develop knowledge of and positive attitudes toward CT (Chan, 2021), or enhance the knowledge and disposition of CT process (Butler & Leahy, 2021; Mouza et al., 2017).

Only a few studies have aimed to increase PST's CT skills and conceptual understanding of science concepts. For example, Bati (2022) asked preservice teachers to design algorithms to solve science problems (e.g., designing a thermometer conversion that converts a temperature value from Celsius to Fahrenheit, or vice versa). In another study, preservice teachers worked on using Micro:bit (a tiny circuit board designed to introduce computing to young children) to create a simulation of the moon's phases and using Microcontroller to create a pH meter (Pewkam & Chamrat, 2022).

Nevertheless, these existing studies solely examined the impact of coding activities on PSTs' CT knowledge and understanding, while access to technology, including motivation and actual usage (which can be limited in remote schools), were not investigated. Given that existing initiatives have predominantly focused on large school districts in big cities and that remote regions have not been the center of previous efforts (Guzdial, 2016), PSTs placed in poorer and rural school districts may have limited opportunities to learn how to develop their students' CT skills. This becomes even more problematic given that rural schools tend to have limited access to advanced technology infrastructure as well as opportunities for professional development (Aduwa-Pgiegbaen & Iyamu, 2009; Palamakumbura, 2009; Trinidad, 2007; Wood & Howley, 2012).

Although unplugged activities (e.g., noncoding activities without computers) can provide effective means to support students' CT skills in rural areas with limited technology access (Yuliana et al., 2021), the plugged activities (e.g., coding) can still provide opportunities for students to make multiple attempts and use various problem elements to decode challenging tasks and to develop, test, and refine solutions. Thus, while it is essential to provide equitable CT opportunities via plugged activities in teacher education programs whose PSTs are placed in rural school settings, the efforts need to consider potential digital divide barriers.

Information Communication Technology Access

Digital divide is not just about physical access to technologies but also related to an individual's motivation, skills, culture, and attitudes toward using information communication technology (ICT: DiMaggio & Hargittai, 2001). To better conceptualize and study the digital divide, van Dijk (2005) conceptualized an ICT access model with four distinct levels, which includes motivation, physical, skills, and usage. The first level refers to users' needs and motivation to use technologies. Next comes physical access in the form of having technologies. Skills access as the third level is about possessing skills to use technologies. Usage access, the last level, refers to the applications and usage frequency.

Van Dijk (2005) argued that unequal access at these levels would limit the degree of participation in society. Extending this theory to computational thinking, PSTs with unequal access levels would likely have limited participation in efforts to learn and teach CT and, consequently, be less likely to help develop the CT skills of the future workforce. While teacher education programs should be integral to helping PSTs' preparation in this aspect, the ways specific course activities can, in fact, impact PSTs' CT access have yet to be examined. As a preliminary step, the current study examined how a specific workshop, designed to infuse CT in a science methods course, influenced PSTs' motivation, skill, and usage access to CT and CT tools. The specific research questions within this research focus included the following:

- RQ1. Does participating in the CT-infused workshop influence PSTs' motivational access to CT and CT tools when their preexisting motivational, physical, skill, and usage accesses are controlled for?
- RQ2. Does participating in the CT-infused workshop influence PSTs' skill access to CT and CT tools when their preexisting motivational, physical, skill, and usage accesses are controlled for?
- RQ3. Does participating in the CT-infused workshop influence PSTs' usage access to CT and CT tools when their preexisting motivational, physical, skill, and usage accesses are controlled for?

Science Pedagogy for PSTs

Despite the potential of CT as a problem-solving approach in education, the skepticism over its ambiguous definition and the limited evidence that it can transfer to other areas beyond computer science (Denning, 2017; Guzdial, 2015) raise possible challenges for educators regarding understanding and using it as part of their pedagogy. Because a successful integration of technological innovations in teaching requires not only the understanding of the technology but also the content-specific pedagogical knowledge (Mishra & Koehler 2006), how PSTs' understanding of CT may be connected to their pedagogical approach in teaching is, thus, essential to study as well.

For the past decade, the development of the NGSS (NGSS Lead States, 2013) has prompted challenging shifts for teaching science that have aimed not only to support student learning of disciplinary core ideas but also to engage them in scientific and engineering practices and to help develop an understanding of concepts across different domains of science. Regarding teacher education programs responding to such shifts, one recommended key strategy is to involve preservice teachers in full inquiries where they can develop science and engineering practices via data collection, analysis, explanation, and communication (Bybee, 2014). One of the ways to provide preservice teachers with such inquiry-based teaching and learning opportunities is the use of the 5E Model (Bybee, 2015b), a widely accepted inquiry-based instructional model for teaching science conceptual understanding (Contant et al., 2018), which has also been extensively researched in teacher education (Kazempour et al., 2020).

Building on the Learning Cycle, an earlier inquiry-based model, the 5E Model emphasizes five distinct phases of learning – Engage, Explore, Explain, Elaborate, and Evaluate (Bybee, 2015a). The focus of the Engage phase is to promote students' curiosity about and interest in the topic while helping them make connections to what they already know about it. Regarding CT, this phase may provide the problem of interest, which would be decomposed for enhanced understanding of the problem. During the Explore phase, students are given opportunities to design and conduct investigations about the topic while they are guided to explain and share their understanding from such experiences in the Explain phase. The Explore phase may be conducive to data practices of CT (Weintrop et al., 2016), while the Explain phase may be ideal for engaging students in recognizing patterns as part of data analysis.

Students also broaden their newly gained understanding by applying it to new issues or aspects of the topic in the Elaborate phase. Because the Elaborate phase is ideal for encouraging interaction with further sources, including web-based simulations (Bybee, 2015b), students may also engage in the modeling and simulation practices of CT (Weintrop et al., 2016) in this phase. During Evaluation, which can occur concurrently with any previous phases, students are engaged in self-evaluation while teachers monitor their progress and assess their understanding. Regarding CT, students' efforts in debugging the encountered problems and analyzing their solutions may provide self-evaluation opportunities.

Although the 5E Model can enhance PSTs' understanding of the inquiry-based instruction (Hanuscin & Lee, 2008) and certain phases may be conducive to supporting CT processes and practices, only a few studies and examples have explicitly described CT in lessons designed based on the 5E Model. For instance, a piloted lesson in a secondary school setting involved the use of physical computing (Arduino software and a pulse sensor) to measure a heartbeat and plot it via a spreadsheet program during the Explore phase (Newland & Wong, 2022).

Another example in an elementary school setting (Nolting et al., 2021), focusing on placing objects in the path of a beam of light, engaged students in a plugged activity (e.g., navigating a physical maze layout on ground made of different colored fabric sheets) during the Explore phase and in an unplugged activity (e.g., programming a puzzle game where a bot moves to different locations that light up).

While such uses of the 5E model have been reported to benefit students' mastery of CT skills and concepts (Gao & Hew, 2022), CT processes (e.g., automation) exemplified in in-service teachers' lessons based on the 5E Model were yet to be sufficient (Mumcu et al., 2023). Further, in-service teachers' challenges, such as limited computer science and programming knowledge and the difficulty in keeping students focused on the computer science tasks (Yadav et al., 2016), may even be more problematic for future teachers who have a limited teaching repertoire.

As such, the ways PSTs connect their newly gained understanding of CT with the 5E Model needs to be explored. As an initial step, the current study aimed to examine the relationship between PSTs' exposure to the CT-infused workshop and their lesson plans. As described in the Methods section later, the participating PSTs in the current study developed lesson plans according to the 5E Model throughout the semester and then were asked to modify the plans based on their experiences with and understanding from the workshop provided. The specific research questions, in this regard, include the following:

- RQ4. What is the relationship between PSTs' participation in the CT-infused workshop and the workshop ideas that they incorporate in their lesson unit modifications?
- RQ5. What is the relationship between PSTs' participation in the CT-infused workshop and the phases of 5Es that they modify in their lesson units?

Methods

Participants

Participants included all of the 3rd-year PSTs (N = 43) from the two sections of an elementary education science method course (taught by the first and second authors) in a teacher education program at a mid-Atlantic university in a largely rural state nestled in the Appalachian Mountains. The two intact classroom sections were randomly assigned to either a control group or an experimental group. The experimental group attended a CT-infused workshop. There were 23 participants in the control group and 20 in the CT-infused group.

The course introduced the PSTs to the teaching and learning of elementary school science through in-class activities that were designed to help them unpack the NGSS, analyze student thinking, revise and teach an existing science lesson in their placement schools, and design and modify a full science lesson unit based on the 5E Model. The PSTs spent around 17 hours per week in their placement classrooms during the semester.

Research Design

The research study was guided by a pre- and posttest quasi-experimental design (Creswell, 2003). At the beginning of the semester, the PSTs were introduced to the study. Those who agreed to participate completed an online presurvey, which took approximately 20 minutes on average. During the semester, they completed various course activities, which are described in a subsequent section. The link to the postsurvey with the same questions was emailed to the PSTs at the end of the semester (see the Data section for the details about the survey questions).

Class Activities for All Students

The course activities that participants in both the control and the CT-infused groups completed included (a) attending the weekly class sessions, (b) conducting an interview with a student from placement classroom to assess children's ideas and thinking about scientific phenomena, (c) revising, teaching, and reflecting on an existing science lesson plan, (d) attending a few workshops offered by guest speakers on digital technologies (DigTech), garden-based learning (GBL), and water resource education (Water), (e) developing a cohesive lesson unit that contains the five phases of a learning cycle (Engage, Explore, Explain, Elaborate, and Evaluate), (f) modifying the 5E lesson unit based on any of the workshops attended, and (g) practicing the phases of the 5E Model by conducting simple experiments on water movement in plants.

Besides the additional workshop sessions on CT, all the classroom activities were kept the same for both sections of the course. The two sections were taught by two instructors who met on a weekly basis to discuss and plan each week's lesson. For all of the in-class sessions, the instructors used the same lesson plans. They provided the PSTs with the same instructions and examples regarding completing each of the course assignments (Items b, c, e, f, and g in the prior paragraph).

All of the workshop sessions except for the one focusing on CT (see next section) were offered by the same guest speakers, who had provided the sessions in the previous year. Also, while the PSTs could interact with those in the other section outside the class time, it would be unlikely for the treatment group to digest the content of the CT workshop, without accessing and carefully reviewing the workshop files, practicing coding, modifying the sample projects, and discussing the lesson ideas.

CT-Infused Workshop for the Treatment Group

In addition to completing the activities described in the previous section, the PSTs in the treatment group participated in two more workshop sessions that focused on integrating CT activities in teaching science. Each session was offered by the first author and lasted 75 minutes over 2 weeks. Table 1 outlines the scope of the additional workshop activities for the treatment group as well as the activities completed by all PSTs:

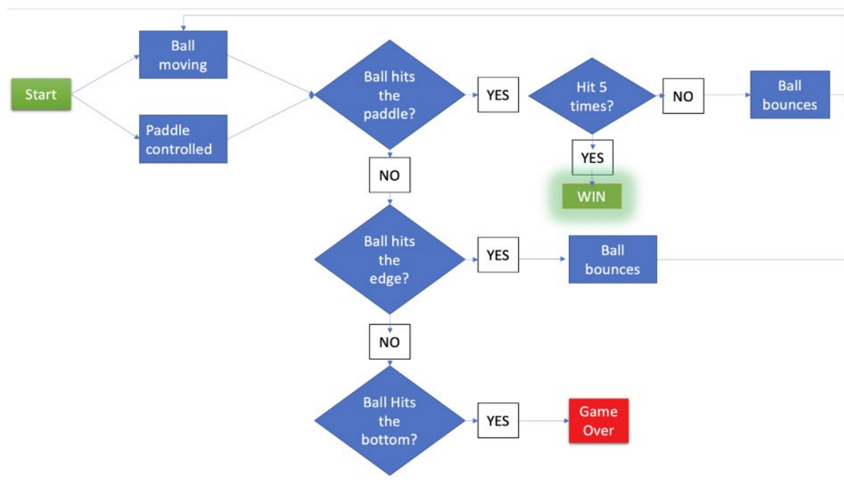
Table 1
Course Activities for Participants

Activities
Class Activities for All Students
- Attending the weekly class sessions. - Conducting an interview with a student from placement classroom to assess children's ideas and thinking about scientific phenomena. - Revising, teaching, and reflecting on an existing science lesson plan. - Attending a few workshops offered by guest speakers on digital technologies (DigTech), garden-based learning (GBL), and water resource education. - Developing a cohesive lesson unit that contains the five phases of a learning cycle (Engage, Explore, Explain, Elaborate, and Evaluate). - Modifying the 5E lesson unit based on any of the workshops attended. - Practicing the phases of the 5E model by conducting simple experiments on water movement in plants
CT Workshop for Treatment Group Only
Participating in two additional workshop sessions that focused on integrating CT in teaching science. **Session 1 – CT and Game Design:** - CT process and its problem-solving nature. - Visual programming as a means to practice CT by demonstrating how to design a simple game in the Scratch interface (https://scratch.mit.edu/projects/677212612). - Example game ideas on science content (https://drive.google.com/file/d/1qpj35ZaiO84m0x03IRRmPLxMQH02IK6O/view?usp=sharing). - Discussion on how simulations may be connected to NGSSs and science concepts. **Session 2 Practice CT via Simulation:** - Further opportunities to practice coding via simulation (voltage, https://scratch.mit.edu/projects/503738063, population, https://scratch.mit.edu/projects/732509780, and oil spillage, https://scratch.mit.edu/projects/226105520). - Discussion on contextual issues that CT may be used for - Development of a simulation on Food Access (https://scratch.mit.edu/projects/505345939). - Discussion on how simulations may be connected to NGSSs and science concepts.

Session 1 – Introduction to CT and Game Design

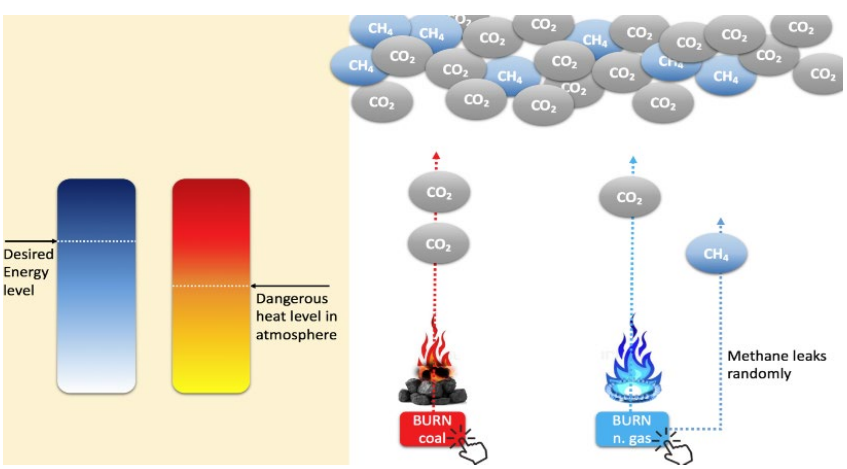
The first session introduced CT, highlighted its importance in education, exemplified its specific processes, mentioned existing computer science education initiatives, and emphasized its problem-solving nature. The session also introduced visual programming as a means to practice CT by introducing game design tenets (e.g., goals, rules, assets, scoring, mechanics, and space), creating a flowchart of the game sequence (see Figure 1), and demonstrating how to design a simple game in the Scratch interface (see https://scratch.mit.edu/projects/677212612).

Figure 1
Flowchart of the Game Sequence



For the next 30 minutes, the PSTs were prompted to identify the functions of various coding blocks used to develop their versions of the game by following a pdf version of a book chapter (Marji, 2014) that describes the steps of creating the game in Scratch interface. Toward the end of the session, another example game idea on science content was briefly presented (Figure 2), which focused on reaching a desired level of energy with minimal greenhouse effect depending on the kinds of fuels selected to be burned (e.g., natural gas versus coal). The game was later followed by a discussion where the PSTs were prompted to reflect on how coding may be related to NGSSs regarding the science and engineering practices, cross-cutting concepts, and disciplinary core ideas.

Figure 2
Example Game Idea



Session 2 – Practicing CT via Simulation

The second workshop session on CT provided further opportunities to practice coding via simulation. It started with a presentation of two simulations in Scratch. One simulation focused on the relation among voltage, current, and resistance (see https://scratch.mit.edu/projects/503738063). The other simulation represented the population of different animals (e.g., fox and rabbit) changing over time based on initial population numbers and the rates of reproduction and death (see https://scratch.mit.edu/projects/732509780).

The PSTs were then prompted to practice representing the equations by using the variables in Scratch projects that did not have any coding. A comparison between simulation process (hypothesis formation → testing → interpretation) and game design tenets (e.g., goals, rules, assets, scoring, mechanics, and space) was presented to make the connection to the first workshop. Next was a presentation of contextual issues that CT may be used for besides the cognitive learning benefits that such simulations can offer.

We then presented another simulation that we had developed previously (see https://scratch.mit.edu/projects/226105520), which displayed how modifying factors such as dispersant (cleaning agent) amount and the level of exposure to sunlight impacted the time needed to clean the oil spill in a given ocean region. Following the simulation, an overview of contextual issues more specific to West Virginia (WV), including poor health status and food access, was provided.

To show how CT can be used for contextual issues and to provide the PSTs with a practice opportunity, another Scratch project, which simulates how the food access varies depending on the location and the kind of food retailers in a given county, was displayed (see https://scratch.mit.edu/projects/505345939). Participants were asked to run the simulation over a certain number of times, generate data and graphs in a spreadsheet, and identify the equation used in the simulation for the food access index. After 15 minutes, they shared, discussed, and compared their equations and were prompted to consider other factors (e.g., family income) impacting food access. Similar to the first session, the second session ended with a discussion on how simulations may be connected to the NGSS and may help teach science concepts.

Both workshop sessions were designed to highlight CT. The connections between the main workshop activities (game design and simulation) in two sessions and the particular CT processes are presented in Table 2.

Table 2
CT Processes Present in Two Main Activities of Workshops [a]

Cnfrt.	Decomp.	Pattern Rec.	Abstraction	Algor. & Autom.	Analysis
Session 1: Game-design activity					
How to make a pong game	Identifying the game elements	Recognizing and determining how the game elements interact with each other	Generating and determining a generic code for the angle needed for the bouncing effect for a given ball direction	Developing codes for the interaction between ball, paddle, and scoreboard	Modifying the codes to troubleshoot any issues
Session 2: Simulation activity					
How to find out food access levels in given two counties	Identifying causes of food access and focusing on geography as a factor	Running simulation multiple times, and identifying the food access value changing differently in each county	Generating data after each simulation run and using excel to generate the equation used to display the food access levels	Turning the identified equation to the codes used in the simulation	Planning how to take into account other factors such as income in the equation
[a] Barr et al., 2011; Grover & Pea, 2013; Wing, 2008					

Data

The first three research questions focused on the impact of the CT-infused workshop on PSTs' CT access. A survey instrument with multiple scales that we had developed and adapted in our previous work (Goh & Kale, 2015; Kale et al., 2018; Soomro et al., 2017) based on the conceptualization of ICT access (van Dijk, 2005) was used to measure the CT access. Following is a detailed description of what the survey measured.

Motivational Access

Motivational access refers to the willingness to learn and use interventions (van Dijk, 2005), which reflects how people perceive the relevance and usefulness of the interventions to their own lives (Hulleman et al., 2010). We asked PSTs to specify their agreement with statements about the usefulness and relevance of CT and CT tools to their teaching efforts and everyday lives (1 = *Strongly disagree* to 5 = *Strongly agree*). The following is an example item in the survey: "I can see how being able to teach computational thinking in education applies to my future career." The five items created a motivation access index for CT (Cronbach's alpha = 0.93) and CT tools (Cronbach's alpha = 0.90), with acceptable levels of internal consistency reliability (according to Nunnally, 1978).

Physical Access

Physical access, essential to the development of technology skills, refers to the possession of technologies (van Dijk, 2005). To measure it, we asked three questions. The first question asked PSTs whether they had access to certain technologies at home or at placement school, such as desktops, laptops, internet, smartphones, tablets, gaming devices, and robotic kits. An index for a variety of technologies accessed was computed from this list (Cronbach's alpha = 0.72), with internal consistency reliability close to acceptable level (Peterson, 1994; Tavakol & Dennick, 2011). The second question asked whether PSTs had access to computer labs, laptop carts and tablet carts in their placement school settings. The third question asked how feasible it was for PSTs to install software on placement school technologies (1 = *I am not allowed to request software to be installed* to 5 = *I can install software myself*).

Skills Access

Skills access is about abilities to operate and manage computer and network services (van Dijk, 2005). To measure it, we asked PSTs to specify their agreement regarding their ability, confidence, and knowledge in designing and teaching lessons using technologies to promote students' CT skills (1 = *Strongly disagree* to 5 = *Strongly agree*). The following is an example item in the survey: "I think it will be easy for me to design a lesson to teach computational thinking." The six items created a skills access index for CT (Cronbach's alpha = 0.88) and CT tools (Cronbach's alpha = 0.86). We also asked PSTs about their familiarity with CT (1 = *Not familiar* to 5 = *Extremely familiar*) and how prepared they were to integrate CT in their teaching (1 = *Not at all prepared* to 4 = *Very prepared*).

Usage Access

Usage access, the final stage, is about one's actual use of various technologies and applications (van Dijk, 2005). To measure it, we asked how often PSTs used computational thinking techniques and tools in their daily life and teaching (1 = *Never* to 5 = *Daily*). The following is an example item in the survey: "I teach how to use computational thinking tools in my placement school." An index based on four items indicated acceptable internal consistency for computational thinking (Cronbach's alpha = 0.88) and computational thinking tools (Cronbach's alpha = 0.94).

The fourth and fifth research questions focused on the relationship between PSTs' exposure to the CT-infused workshop and their 5E lesson unit modifications. The data for these questions included a written assignment in which the PSTs described how they might modify their 5E lesson unit developed throughout the semester. Specifically, the instructions for the assignment listed all the workshop sessions provided in the respective course section and prompted the PSTs to focus on one of the 5Es in their lesson units that they thought could be modified based on the ideas from any of the workshop sessions. They were then asked to submit to the course learning management system the modified E from their lesson units, including description of the modifications.

Data Analysis

While a common occurrence in data collection, missing data can affect the validity and reliability of findings (McKnight et al., 2007, pp. 1-16). The percent of missing values in our study across all numerical variables varied between 3 and 40%. In total, 222 out of 3,139 responses (7%) recorded for all numerical variables from the participants (N = 43) were missing. To mitigate the chance of incomplete data affecting this study, we first tested the data to determine if each response variable was missing completely at random (MCAR) using Little's (1988) MCAR test. For the data that were determined to be MCAR, we then applied multiple imputation by chained equations using predictive mean matching. These calculations were conducted using the package mice (van Buuren & Groothuis-Oudshoorn, 2011) and dplyr (Wickham et al., 2022) in the statistical software platform R (R Core Team, 2021). Of the 15 variables of interest, three could not be imputed.

A series of t-tests on presurvey measures was conducted to examine if the two intact classroom sessions were similar at the beginning of the semester. Results, as seen in Table 3, revealed no significant difference between the control and CT-infused groups regarding their CT access prior to the intervention.

Table 3
Mean Scores and SDs Between the Condition Groups at Presurvey (N = 43)

Group	Control (*n* = 23) Mean (*SD*)	CT_Infused (*n* = 20) Mean (*SD*)	*t*	*p*
Motivation (CT)	19.43 (4.17)	21.25 (2.34)	1.725	0.092
Motivation (CT tools)	21.65 (2.64)	21.45 (2.34)	-0.269	0.789
Physical (tech variety)	7.83 (3.85)	6.85 (3.07)	-0.911	0.368
Physical (school tech)	2.52 (0.73)	2.10 (0.97)	-1.625	0.112
Physical (install software)	3.09 (1.38)	2.55 (1.23)	-1.335	0.189
Skills (CT)	16.18 (4.00)	16.45 (4.36)	0.197	0.845
Skills (CT tools)	17.13 (4.35)	15.20 (4.96)	-1.360	0.181
Skills (familiarity)	1.86 (0.77)	1.90 (0.72)	0.157	0.876
Skills (preparedness)	2.25 (0.88)	2.79 (0.99)	1.753	0.088
Usage (CT)	10.57 (4.39)	10.45 (4.24)	-0.087	0.931
Usage (CT tools)	8.70 (4.43)	7.15 (4.02)	-1.190	0.241

For the first three research questions, we conducted ANCOVAs with the postsurvey measures as dependent variables (motivational access for RQ1, skill access for RQ2, and usage access for RQ3), while the presurvey measures on motivational, physical, skill, and usage accesses were used as covariates. For ANCOVAs, the assumptions regarding homogeneity of regression slopes and homogeneity of variance were tested. Planned contrasts were utilized to examine significant main effects (as recommend in Field, 2016).

The analysis of variables' distributions led to some of their transformations as a means to enhance normality and reduce skewness.

Based on Tabachnick and Fidell's (2001) suggestions, a square root transformation on the post measures of Motivational Access for CT Tools, Skill Access for CT, Skills Access for CT Tools, and the reflected postmeasure of Familiarity with CT was applied. A square root transformation on the reflected postmeasure of Preparedness to Integrate CT was used due to its negative skewness.

For the fourth and fifth research questions focusing on the relationship between the PSTs' exposure to the CT-infused workshop and their lesson unit modifications, we examined the written assignments, which included one of the Es they specified from their lesson along with a description of how they modified it based on the ideas from any workshop sessions. We specifically categorized each assignment based on the phases of 5E lessons modified and the workshop that each PST referred to in their descriptions. For RQ4, we counted the number of PSTs whose modifications were prompted by each of the workshop ideas (CT, GBL, DigTech, and Water) and conducted a Chi-square test to examine whether the percentage of the PSTs who chose to incorporate a particular workshop idea in their lesson modifications significantly varied depending on the condition (whether PSTs participated in the CT infused workshop). For RQ5, we counted the number of PSTs who modified Engage, Explore, Explain, Elaborate, and Evaluate, and conducted a Chi-square to examine whether the percentage of the PSTs who chose to modify a particular phase of 5E lessons varied depending on the condition.

Results

All of the students across two sections (*N* = 43) completed both pre and post surveys. Table 4 provides the descriptive statistics on each variable.

Table 4
Mean Scores and SDs on Both Pre- and Postsurvey Measures (N = 43)

Category	Presurvey (*n* = 43) Mean (*SD*)	Postsurvey (*n* = 43) Mean (*SD*)	[Possible Range]
Motivation (CT)	20.28 (3.52)	20.56 (2.46)	[5, 25]
Motivation (CT tools)	21.56 (2.43)	21.42 (2.65)	[5, 25]
Physical (tech variety)	7.37 (3.49)	7.37 (3.49)	[0, 16]
Physical (school tech)	2.33 (0.87)	2.33 (0.87)	[0, 9]
Physical (install software)	2.83 (1.32)	2.83 (1.32)	[1, 5]
Skills (CT)	16.32 (4.14)	20.27 (3.44)	[6, 30]
Skills (CT tools)	16.23 (4.69)	21.00 (3.24)	[6, 30]
Skills (familiarity)	1.88 (0.74)	2.95 (0.78)	[1, 5]
Skills (preparedness)	2.55 (0.97)	3.55 (0.73)	[1, 4]
Usage (CT)	10.51 (4.27)	10.51 (4.27)	[4, 20]
Usage (CT tools)	7.98 (4.27)	9.07 (3.66)	[4, 20]

RQ1-3

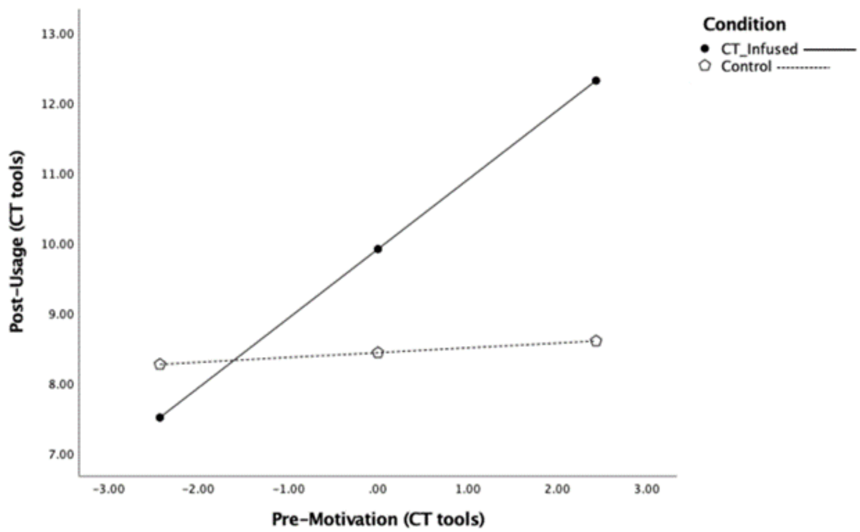
ANCOVAs with the presurvey scores on motivational, physical, skill, and usage accesses as covariates compared the control and CT-infused condition groups' postsurvey motivational, skills, and usage access scores (CT and CT tools). Leven's tests were conducted as well as the potential interactions between any of the presurvey measures. The postsurvey measures were examined to check the assumptions of homogeneity of variance and homogeneity of regression slopes. In cases where these assumptions were violated, ANCOVA results were not interpretable. Instead, we used the PROCESS in SPSS (Hayes 2012, 2013) to run a moderation regression to examine how presurvey measures might influence the effect of condition on postsurvey measures.

Analysis results indicated that after controlling for the effects of the presurvey measures, no significant effect of the condition on the postsurvey Motivation (CT tools) was observed, though the condition significantly affected the postsurvey square root of reflected Skills (Preparedness), $F_{sqrt(ref(Preparedness))}(1, 34) = 7.587$, $p = 0.011$. Rereflecting this variable to correct the direction of the interpretation (Tabachnick & Fidell, 2001) indicated that PSTs who participated in the CT-infused workshop felt prepared to integrate CT in their future teaching ($M = 1.17$, $SD = 0.08$) to a significantly greater degree than those who did not attend the CT-infused workshop (control group; $M = 1.09$, $SD = 0.07$), $F_{re\text{-}ref(sqrt(ref(Preparedness)))}(1, 34) = 6.106$, $p = 0.019$.

Further, we identified a significant moderation effect of presurvey Motivation (CT tools) regarding the effect of condition on postsurvey Usage (CT tools). Based on the coefficients obtained, a regression equation with the significant interaction effect was formulated, corresponding to between a small and medium effect size, $F(3, 39) = 3.278$, $R^2 = 0.201$, $p = 0.031$, $f^2 = 0.042$. The regression equation was as follows: post-Usage (CT tools) = 9.116 - 1.479*(condition) + 0.496*(pre-Motivation (CT tools)) - 0.919*(condition* pre-Motivation (CT tools)).

The R^2 increase due to the interaction effect was 0.081, $F(1, 39) = 4.301$, $p = 0.047$. The procedure also resulted in the values of the post-Usage (CT tools) for three levels of pre-Motivation (CT tools; low, medium, and high), which were used in the simple regression slopes within each condition group (see Figure 3).

Figure 3
Regression Slopes for Interaction Between Condition and Pre-Motivation



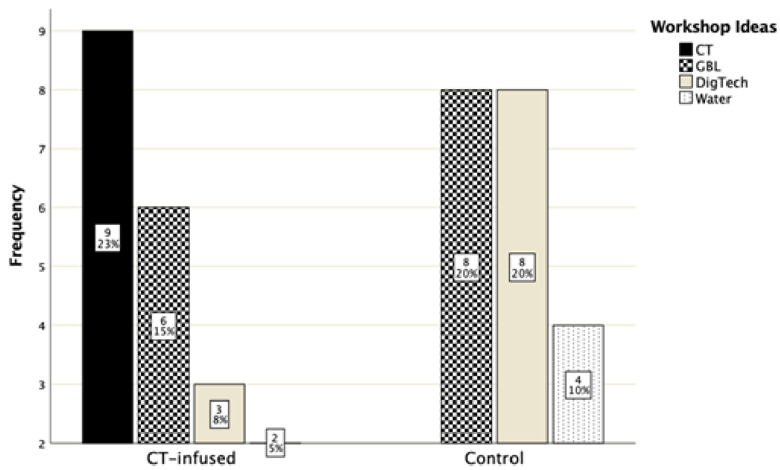
These results revealed that in the control group (dotted line), PSTs' post-Usage (CT tools) level remained the same regardless of their pre-Motivation (CT tools). On the other hand, PSTs who participated in the CT-infused workshop (straight line), had increasing levels of post-Usage (CT tools) at the end of the semester in relation to their Motivation (CT tools) levels at the beginning of the semester.

In other words, in the CT-infused group (straight line), the more relevant and useful that PSTs initially considered computational thinking tools for their current and future teaching, the more likely it was for them to indicate that they used such tools in their daily lives and teaching practices to a greater degree after attending the CT-infused workshop. This effect was not observed in the control group where PSTs did not participate in the CT-infused workshop.

RQ4

The analysis revealed that of all the workshop ideas (CT, GBL, DigTech, and Water) that PSTs chose to incorporate in their lesson modifications, slightly more than one third was GBL (n = 14, 35%), followed by DigTech (n = 11, 27.5%), CT (n = 9, 23%), and Water (n = 6, 15%). The results from the Chi-square test indicated that the percentage of the PSTs who chose to incorporate a particular workshop idea in their lesson modifications significantly varied depending on the condition, χ^2 (3, n = 40) = 12.225, p = 0.007. The adjusted residuals for further analysis (Hinkle et al., 1998) showed that in the CT-infused group, there was significantly a higher percentage of PSTs (9%) than expected who incorporated CT in their lesson modifications (see Figure 4).

Figure 4
Workshop Ideas Incorporated in Lesson Modifications



While no significant variance was observed in the percentage of workshop ideas present in the control group, none of the PSTs here incorporated CT in their lesson modifications, which was not surprising given that they did not attend the CT workshop.

RQ5

The analysis revealed that of all the 5Es that PSTs chose to modify in their lesson units, approximately one third was Explore (n = 13, 33%), followed by Explain (n = 11, 27%), Elaborate (n = 9, 23%), and Engage (n = 7, 17%). The Chi-square test indicated the percentage of the PSTs who chose to modify a particular phase of 5E lessons did not vary depending on the condition (whether PSTs participated in the CT infused workshop), χ^2 (3, n = 40) = 6.290, p = 0.098.

A further analysis focused on the phases of 5E modified in the lesson plans that incorporated CT only. Of the nine phases modified to incorporate CT, almost half (n = 4) were Elaborate, two were Explore, two were Engage, and one was Explain. The descriptions of the modifications indicated that the majority of the PSTs chose simulations (n = 7), and two used game-design, which focused on simulating various scientific concepts including weather conditions, erosion, rock formation, plant growth, falling objects (gravity), object collisions, melting/freezing points, and illumination of objects (lights).

Although no statistically significant pattern was identified, the PSTs' descriptions of their modifications highlighted four kinds of affordances of incorporating CT in their lessons —visualizing understanding, assessment of learning, deepening learning, and motivating students. See Table 5 for the presence of such affordances observed in the descriptions of specific Es modified.

Table 5
CT Affordances Observed in Various Stages of 5E Model

	Engage	Explore	Explain	Elaborate
Visualizing understanding	✓	✓	✓	✓
Assessment of learning	✓			✓
Deepening learning		✓	✓	
Motivating students	✓	✓		

Visualizing Understanding

Regardless of the modified phase, the majority of the PSTs who incorporated CT (n = 7) emphasized the use of CT as a means to visualize the understanding of the concepts, as seen in the excerpts from participants' descriptions. For instance, one participant indicated in the description that "[It will] help the students create a simulation in which they simulate what they saw." Another participant noted, "Students would get to see how a physical experiment could be turned into a simulation and show the same information."

Assessment of Learning

Two participants' modifications made in the Engage and Elaborate phases also referred to simulation but focused on the assessment of learning. One participant mentioned, "With this [simulation], students are free to create their own projects that I can look at and understand their thinking…Students would much rather have something to look at and serves as their proof of learning." Another participant wrote, "It is an alternate way for students to show what they learned to simulate their experiment."

Deepening Learning

Three modifications in the Explore and Explain phases referred to their use of CT as a means to deepen student learning. One participant said, "This could help them to remember the material better." Another said, "It allows the students to think deeper on what they have learned," while the last one noted, "The students are able to expand previous ideas and use the thinking to explain the concepts in a manner that might be relatable to scientists."

Motivating Students

Finally, the incorporation of CT in two modifications (Engage and Explore phases) highlighted its affordance regarding motivating students and increasing their interest. One participant, for instance, explained why they made such a modification: "I wanted students to be a little more engaged." Another participant explained, "If the class and I were to create a game about the rock unit then students might become more interested in the subject."

Discussion

The following sections discuss the findings from the study and present three major themes that emerged from the analysis.

Motivation as the Key

Findings indicated that after the covariates were controlled for, no significant difference was observed between the control and CT-infused groups regarding their motivational access to CT and CT tools. In other words, participating in the CT-infused workshop did not increase PSTs' perception of CT's usefulness for and relevance to their current and future teaching practices. The CT-infused workshop's emphasis on coding with limited connections to PSTs' existing teaching efforts may explain this observation. Although the two workshop sessions introduced CT and ended with discussions on how it may be connected to NGSSs and teaching science concepts, the majority of the time was allocated to coding a game design in the first session and a simulation in the second session.

Without opportunities not only to discuss but also to reflect on CT-infused science lessons, PSTs may have had difficulties in realizing CT's usefulness to their future practices. This assertion also aligns with the existing research, which indicates that providing opportunities to reflect on the relevance of an intervention helps individuals recognize its value and usefulness (Kale & Akcaoglu, 2017; Hulleman et al. 2010).

In the case of PSTs, meaningful reflections on CT would likely require going beyond short discussions by designing and reflecting on learning activities incorporating CT in teaching science concepts. Given the potential time limitations during the in-class sessions, a few weeklong asynchronous group work where PSTs can design, discuss, and reflect on full learning activities with a timeline of detailed instructional events may help promote students' CT and learning of science concepts.

In the workshops, no connection to the existing course assignments and PSTs' current lesson planning was explicitly made, probably making it difficult for PSTs to identify how the workshop may be related to their current teaching efforts. While it would not be feasible to tailor the workshop to each PST's current lesson plan ideas, examples could have been built on topics covered in the course.

For instance, the simulations demonstrated during the workshop focused on electricity, voltage, animal population, and an oil spill. Instead, developing simulations regarding the impact of various factors (e.g., heat and light) on germinating different kinds of seeds would be more relevant to (a) the main theme of the workshop (e.g., food access), (b) the experiments that the PSTs had been conducting (water-movement in plants) during the semester, and (c) the garden-based learning workshop offered by a guest speaker.

Further, the lack of connection to the existing course assignments probably made it difficult for PSTs to identify how the workshop may be related to their current teaching efforts. For example, the simulations demonstrated during the workshop focused on electricity, voltage, animal population, and oil spill but made no reference to any existing course work. Instead, two related course activities that included (a) the experiments that the PSTs had been conducting (water-movement in plants) during the semester and (b) the garden-based learning workshop offered by a guest speaker that emphasized a similar NGSS (5-LS2-1. Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment) and could have been connected to the workshop content. This may involve demonstrating simulations or having the PSTs create ones regarding the impact of various factors (e.g., heat and light) on germinating different kinds of seeds, which would be more relevant to the activities.

Although PSTs' motivation access was not influenced by the CT-infused workshop, the findings indicated that it played a crucial role in their usage access. Participating in the CT-infused workshop was beneficial to PSTs' usage access in relation to their initial levels of motivational access. Specifically, the more relevant that PSTs initially found CT tools to their teaching, the more likely it was for them to use such tools if they attended the CT-infused workshop.

While this observation is promising regarding the impact of the CT-infused workshop on increasing usage access, it also suggests the need for developing PSTs' motivational access prior to the workshop. Introducing CT as a problem-solving approach along with examples and reflection activities (Kale & Akcaoglu, 2017) specific to teaching science before conducting the workshop may be useful to help PSTs recognize its value, and consequently increase their motivational access and likelihood to use CT tools (usage) in their lesson plans and teaching practices.

Prepared But Challenged

Regardless of the PSTs' initial motivation, however, the analysis indicated that the CT-infused workshop enhanced their preparedness to use CT tools in future teaching practices. This finding is encouraging because expectations to successfully complete a given task (i.e., competence) and the value placed on that task (i.e., relevance) have been considered to impact the willingness to start and put efforts into it (Brophy 1999, 2010; Wigfield et al. 2008; Wigfield & Eccles 2000). Further, as found in a recent study (Kartal & Başarmak, 2022), PSTs' self-efficacy in terms of their ability to teach CT contributes to their actual teaching practices. Likewise, the PSTs in the current study who felt prepared to integrate CT tools, may be more willing to do so in future practice when it comes to teaching in classroom settings, especially if they recognize the value of CT.

This assertion, however, was partially supported in the current study. As discussed earlier, PSTs' initial perceptions of CT tools' usefulness to teaching, in fact, contributed to their usage of such tools. On the other hand, no such effect of skills on usage was revealed in the analysis. In other words, while the CT-infused workshop increased PSTs' preparedness to integrate CT tools, the perception of preparedness did not make a difference in their reported use.

Another aspect of skill access measured in the study may explain this observation. As described in the methodology section, besides the preparedness and familiarity, we measured PSTs' confidence in designing lessons promoting CT. As the analysis revealed, the CT-infused workshop did not increase PSTs' confidence and knowledge in this regard. Given that the workshop contributed to PSTs' preparedness only, this result may imply that PSTs were likely to view CT-infused teaching as a rather challenging task. Although two 75-minute workshop sessions introduced CT and provided opportunities to practice coding and discuss CT's connection to science, more opportunities may be necessary to help PSTs develop confidence and knowledge.

Because of the potential time limitations in the course schedule, such opportunities may need to go beyond the classroom settings. For instance, PSTs may attend live online sessions (e.g., via Zoom) or follow asynchronous online tutorials to practice modifying the codes presented or to complete relevant coding tasks on their own, while they may also be prompted to remix PSTs' projects, ask questions, or troubleshoot difficulties encountered by others in a discussion forum.

CT Appealing But Not Linked to Pedagogy

Besides the positive impact on skill (preparedness) and usage access (CT tools), the CT-infused workshop also appealed to the PSTs. As the analysis revealed, compared to other workshop ideas, attending the CT-infused workshop increased PSTs' likelihood to incorporate CT in their lesson modifications. Given the emerging emphasis on computer science education and CT in school settings, this finding is also promising and highlights the effectiveness of the workshop in enabling PSTs to consider CT in their instructional practices.

Nevertheless, there was no clear relationship between attending the CT-infused workshop and the phases of 5E Model that the PSTs chose to modify in their lessons. This finding may not be surprising given the lack of connection to the 5E Model present in the workshop. While the PSTs were developing 5E lesson units in the course, no specific references to the 5E Model in relation to CT were present in the workshop. Because a successful integration of technological innovations in teaching requires not only the content but also pedagogical knowledge (Mishra & Koehler, 2006), relating CT processes to the 5E Model as a pedagogy for teaching science content will be a necessary step.

An example activity to illustrate such an approach for future workshops would focus on the growing food simulation idea, where various factors (e.g., heat and light) are being examined regarding their impact on germinating different kinds of seeds. The activity may start with a discussion on the conditions impacting germination, which would be followed by using a developed simulation where PSTs could make choices regarding absence or presence of heat maps, grow lights, and two kinds of cucumbers (Access the sample simulation of this activity at https://scratch.mit.edu/projects/545709934).

PSTs, in groups, would then be asked to run the simulations over a certain amount of time (e.g., 20 times) to generate a data set (e.g., number of days required for all seeds to germinate), enter it in an electronic spreadsheet, and generate and compare their graphs for identifying the impact of the choices they make in the interface (heat map, light, and seed kind). This activity later could be even elaborated by another one where PSTs would discuss a new factor (e.g., water amount) and code its effects (e.g., based on a given set of data and an equation to be generated) in a simulation. They could then examine other group's graphs and even remix their completed simulations. Table 6 outlines the learning tasks and CT processes that can be engaged within the 5E Model. Such an example can be used by future studies and workshops in order to relate CT processes to the 5E Model as a pedagogy for teaching science content.

Table 6
Grow Food Learning Tasks, CT Practices, and CT Processes Within 5E Model

Category	ENGAGE	EXPLORE	EXPLAIN	ELABORATE	EVALUATE
Learning Tasks	Discuss conditions impacting germination	Run simulation multiple times to create data and identify equation	Reflect on data and discuss equations	Focus on a new factor, remix simulation, and modify equation	Peer-evaluate progress
CT Processes	-Problem confrontation	-Decomposition -Pattern recogn.	-Analysis	-Algorithm & Automa.	-Analysis

Further, although no statistically significant pattern was identified, almost half of the PSTs who incorporated CT in their lessons chose the Elaborate phase to modify. This observation may indicate that the PSTs might tend to consider CT as an opportunity for students to expand their newly gained understanding. On the other hand, applying the newly gained understanding in new context and issues, a tenet of Elaborate phase (Bybee, 2015a), may not be fully reflected in their perceptions.

As revealed, the PSTs who modified the Elaborate phase highlighted simulation as a means to enable students to generate a different version of what they already created in previous activities and experiments. Although activities engaging students in generating the same content in different modalities can be useful, for instance to help students explain prior observations (Explain), the transfer of learning may be limited (Eisenkraft, 2003). As such, emphasizing the importance of allowing students to apply their knowledge in new issues and context will be necessary to helping PSTs consider CT's affordances that serve the purpose of the Elaborate phase.

Also, while other affordances of incorporating CT in the lessons were also identified in the modifications, such as assessment of learning, deepening learning, and motivating students, a deeper discussion of such affordances in relation to the phases of 5E Model will be also essential in helping them connect CT to the science pedagogy.

Conclusion

The purpose of this research project was twofold. The first purpose was to examine how a specific workshop, designed to infuse CT in a science methods course, may influence PSTs' access to CT. Findings revealed that after the covariates were controlled for, attending the CT-infused workshop did not impact PSTs' motivational access, though it made them feel prepared to integrate CT in their future teaching to a significantly greater degree. Further, the more relevant and useful that PSTs initially considered computational thinking tools for their current and future teaching (motivational access), the more likely it was for them to indicate that they used such tools in their daily lives and teaching practices to a greater degree if they attended the CT-infused workshop.

The second aim was to examine the relationship between PSTs' exposure to the CT-infused workshop and their lesson plans that were designed based on the 5E Model. Findings indicated that compared to other workshop ideas, attending the CT-infused workshop increased PSTs' likelihood to incorporate CT in their lesson modifications. Though there was no relationship between attending the CT-infused workshop and the phases of 5E that the PSTs chose to modify in their lessons, the Elaborate phase seemed to be more preferable than other phases to incorporate CT as a means to expand students' understanding.

Based on the observed findings, potential course design ideas and implications regarding increasing PST's CT access included (a) using asynchronous activities to reflect on the connection between CT and lessons including the relevant NGSSs (b) building example simulations on the topics covered in the course, (c) providing further opportunities to practice coding, (d) introducing CT earlier in the semester prior to the workshop to help PSTs recognize its value, and (e) relating CT processes and affordances of CT to the 5E Model as a pedagogy for teaching science content.

As with any research project, the current study has limitations, which should be taken into account for future work. First, participants' CT access was measured both at the beginning and at the end of the semester while it was possible for the CT access to change during the semester such as between the two CT-infused workshop sessions. As such, examining CT access more frequently, such as right after each CT session, may provide future research work with a better understanding of how it changes over time and how each session may impact this construct.

Second, the findings were specific to the PSTs who were at the 3rd year of the teacher education program, when they had relatively limited experiences with and knowledge of teaching in their placement schools (17 hours per week) compared to the 4th-year students who had full time placement (35 hours per week). As PSTs spend more time in field placement and take more courses at later stages of their program, they develop more skills in teaching and using technologies, further shaping their perceptions of technologies specific to the content areas and potentially increasing their CT access. Thus, repeating the current study with multiple cohorts at multiple stages of the program of studies will generate findings that allow for identifying the changes in PSTs' CT access throughout the program. With these shortcomings in mind, the current research study offered significant insights about the effects of the CT-infused workshop and provided potential course design implications to further increase PSTs' CT access.

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