Physics Teachers’ Motivations to Learn Computational Thinking as a Re-novicing Experience

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Integrating computational thinking (CT) into high school physics requires physics teachers to develop specialized pedagogical content knowledge of computing and content integration. We describe this as a re-novicing experience, in which teachers build and act upon knowledge at the intersection of physics, computation, and pedagogy. We observed this re-novicing in a Python workshop for physics teachers ($n = 23$) from three countries. Teachers participated in computational learning activities in Jupyter Notebooks with the goal of developing their capacity to integrate Python in physics applications. In this exploratory study, we describe a framework for integrated CT professional learning and report teacher responses to a post-workshop survey about their motivations for participating in this re-novicing process. Their motivations included needing to learn essential programming features and an intrinsic motivation to transform how they teach physics. These findings suggest that professional learning for CT integration needs to interweave computing content with pedagogical applications.
Computational Thinking (CT) is the processes of using logic and algorithms to formulate problems and construct solutions that a computer can carry out [1]. In physics practice and education, computer programming is the vehicle by which such solutions are enacted. The integration of CT [2–9] into undergraduate physics education is an established practice [10–13]. However, because this integration is a relatively recent development [14] and has yet to fully reinforce CT as relevant for future educators [15], the integration of CT into the high school physics context is still in the beginning stages [8, 16–20]. As CT integration is not required by any district or curriculum found in the United States, integrating CT is an instructional choice that requires teachers to learn computer programming after graduating.

The term re-novicing has been used to describe when teachers are assigned to subjects or grade levels for which they lack disciplinary content knowledge or discipline-specific pedagogies [21–23]. A teacher’s decision to learn how to integrate computer programming within physics instruction is a form of re-novicing.

The re-novicing process we discuss in this paper begins with learning computing practices and proceeds toward full physics-CT integration [24]. This process is understandably challenging, and supporting teachers requires understanding the factors that might motivate them to begin learning about CT integration and sustain their implementation of it. In this paper, we ask the research question, What motivates physics teachers to learn computing as a re-novicing experience?

To understand teacher motivations, we consider three domains of learning required to integrate CT with physics as a disciplinary subject. Grover [25] frames the integration of CT with a disciplinary subject (like physics) by extending definitions of technological pedagogical content knowledge (PCK) [26] to include the subject domain and computing as distinct but overlapping fields. As depicted in Figure 1, this CTIntegration framework depicts three categories of PCK: (1) Physics Content & Practices (such as one might learn in an undergraduate physics program), (2) Computing Content & Practices (such as one might learn in an undergraduate computing program), and (3) Pedagogy (such as one might learn in an undergraduate education program). The intersections in this framework highlight the interdisciplinary knowledge bases of Physics-Computing Integration (1 ∩ 2, how to solve a physics problem using iterative numerical calculations), Computing PCK (2 ∩ 3, how to teach programming practices), Physics PCK (1 ∩ 3, how to teach physics), and Physics-CT Integration PCK (1 ∩ 2 ∩ 3, how to teach physics and computation in an integrated manner that enables new avenues of learning [27]).

In our prior work [24], we theorized a pathway of re-novicing (dashed arrow in Figure 1) to describe individual teachers’ professional learning needs through these domains. This pathway begins by introducing computing content and practices (Circle 2 in Figure 1), experiencing physics applications of computing (Intersection 1 ∩ 2), and developing the PCK necessary to deliver physics-CT integrated learning strategies in their courses (Intersection 1 ∩ 2 ∩ 3). For example, suppose a high school physics teacher wanted to integrate CT into their unit on projectile motion. They must first learn the necessary computing practice of iterative loops (Circle 2), then apply an iterative loop to automate a numerical solution of the projectile’s motion (Intersection 2 ∩ 3). Finally, they must reflect on how they can teach students to use this approach to understand projectile motion (Intersection 1 ∩ 2 ∩ 3). This re-novicing pathway also helps us categorize teachers’ motivations to integrate CT in physics and thereby provide appropriate professional learning opportunities.

II. RESEARCH CONTEXT

We conducted an online synchronous workshop for high school physics teachers in summer 2022, co-sponsored by the American Association of Physics Teachers [24]. The physics teachers enrolled in the workshop (n = 23) were from 15 different states in the United States and from Canada and Italy. All participants were experienced in-service high school teachers and AAPT members. Their self-reported experiences with computer programming prior to the workshop varied from no experience to formal computing coursework. We structured each day of this three-day workshop to feature
a three-hour morning session and a three-hour afternoon session. During morning sessions, teachers worked in groups of 4-6 in breakout rooms to complete a computational activity designed to be accessible in a high school physics environment. These activities were based in Jupyter notebooks so that teachers could experience the integrated physics/CT curriculum as learners [28] in a collaborative online setting. During afternoon sessions, teachers were offered a choice board of computational integration topics, including assessment of computation-based activities, lab adaptations, visualizations of electrostatics, random number generation, quantum applications, and the use of external data sets. These sessions were designed to be exploratory, with each group working at their own pace and relying on each other’s insights and a facilitator’s feedback.

The learning activities were designed to build teachers’ capacity [29] for CT integration in physics-situated computing applications, and the workshop structure was designed to model computing PCK [30]. This capacity development is a re-novicing experience [21], in which teachers who aspire to integrate new content may struggle in similar ways to new teachers as they negotiate gaps between what they already know and what they have yet to learn. Professional learning that supports teachers on this pathway of re-novicing requires an understanding of their motivations to integrate CT.

III. METHODOLOGY

We collected survey responses from \( n = 23 \) teachers who participated in a three-day workshop about physics applications of programming in Python. In this paper, we focus on their responses to the first survey question, “What first motivated you to participate in the workshop?” using qualitative content analysis. The first author used first cycle open concept coding [31] to identify common themes among responses. This author relied on his observations as a workshop leader to contextualize the teachers’ comments. The three authors discussed these open codes and agreed that they adequately characterized the teachers’ responses. We then used the domains of our adapted CTIntegration framework [24] as a set of second cycle provisional codes [31] to map teacher motivation onto professional learning needs. The first two authors independently coded the first cycle concept codes using the circles and intersections (see Figure 1) by re-examining the associated teacher responses. To increase the credibility and dependability [32] of our qualitative findings, the third author provided a peer debriefing [33] of the data analysis using his expertise as a STEM education researcher. The first and second author responded to the third author’s questions and revised coding accordingly until consensus was reached.

IV. RESULTS: TEACHERS’ DESCRIPTIONS OF MOTIVATION

Here, we discuss themes in teachers’ responses to a post-workshop survey question: “What first motivated you to participate in the workshop?”

A. First-Cycle Thematic Coding

In our first cycle coding, we identified seven conceptual themes (bold text below and first column of Table I) among the teachers’ responses. Some responses exhibit multiple themes, so the sum of the numerical values reported below exceed our \( n = 23 \) participants.

Four teachers expressed an interest in beginning to learn programming, which indicated that the teacher wanted to learn programming for the first time. These teachers felt they were complete novices with respect to computing content and practices. Four other teachers explained that they wanted to build on their prior programming experiences as learners. These responses indicated prior experience with programming but an interest in refreshing or expanding this knowledge. This finding supports prior research that reveals how experiencing CT as an undergraduate physics student may be insufficient for a physics teacher to integrate CT into their teaching [15], and how physics teachers learn to integrate CT by exploring their own interests and capabilities first [20].

The greatest number of teachers (13 out of 24) described wanting to teach physics differently thanks to the affordances of computational approaches. Some teachers described this as a long-term goal, or as an opportunity created by curricular changes, or a desire to improve the quality of teaching and learning. Three teachers expressed an interest in building on prior programming experience as teachers. These responses indicated either prior experience with integrating CT into a physics class or teaching a computing class. Three teachers expressed an interest in teaching a physics course with computation. These teachers specifically identified CT integration as a central component of an upcoming course, indicating they were already committed to implementing what they learned in the workshop.

Seven teachers described the importance of preparing students for postsecondary STEM courses or professions. These responses highlighted the importance of computing applications in their students’ future education and careers. Two teachers specifically mentioned responding to student interest after students or alumni requested programming-related curricula.

B. Second-Cycle Provisional Coding

In our second cycle provisional coding, we identified where in the CTIntegration framework (Figure 1) each of the
TABLE I. First and second cycle coding of n = 23 teacher responses to survey question: “What first motivated you to participate in the workshop?” First cycle codes summarize themes in teacher responses. Second cycle codes map these themes onto the CTIntegration framework in Figure 1. Nearly all (20 out of 23) teacher comments relate to the central provisional code of Physics-CT Integration PCK.

<table>
<thead>
<tr>
<th>First Cycle Concept Codes (Number of Participants) with Illustrative Quotes</th>
<th>Second Cycle Consensus Provisional Codes (Number of Participants)</th>
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| **Begin to learn programming** (4)  
“I want to familiarize myself with a programming language.” | Circle 2 Computing Content & Practices (10) |
| **Build on prior programming experience as a learner** (4)  
“I decided I needed to get my students into the 2020s and to do so, I had to dust my quarter-century old computing skills off and learn some Python.” | Intersection 2 ∩ 3 Computing PCK (3) |
| **Respond to student interest** (2)  
“I was approached by a former student who had just obtained his undergrad degree, who remarked, ‘your class was great ... it really would have been nice if we had some coding in it as well.’ Honestly, that really lit the fire in me.” | Intersection 1 ∩ 2 ∩ 3 Physics-CT Integration PCK (20) |
| **Build on prior programming experience as a teacher** (3)  
“I have always dabbled in the use of computational physics in my classes, but never had a clear vision as to what it might look like in regards to content, platform/language, etc.” | |
| **Teach physics differently** (13)  
“It has been a goal for a few years to include computational problem solving skills in my physics courses but the barriers to entry felt high... I thought this workshop could give me enough tools to get over my initial hesitations to start something, even if it’s not perfect.” | |
| **Prepare students for postsecondary STEM courses/professions** (7)  
“Alumni from my classes regularly come back from university, internships, etc. indicating that programming experience was essential to their success in STEM post-high school. Or they indicate that they wish they had more exposure to programming skills in high school because much of it is assumed knowledge in their college STEM coursework and they have to figure it out on their own. I want to build my Python skills so that I can add programming seamlessly into courses students are already taking at my school (like Physics).” | |
| **Teach a physics course with computation** (3)  
“I have a certificate in computer programming and have always loved it, but had trouble figuring out how to incorporate it.” | |

first-cycle themes seemed to indicate the teachers’ motivations lie (second column in Table I). We found that three areas (one circle and two intersections) in the framework seemed to describe these themes.

The themes of beginning to learn programming, building on prior programming experience as an learner, and responding to student interest lie within Circle 2, Computing Content & Practices. As described earlier, this category comprises computing knowledge independent of disciplinary applications or pedagogical delivery. These themes indicate a focus on teachers’ need to develop knowledge of programming or students’ expressed need to develop such knowledge. While the teachers attended a workshop designed to deliver and utilize such knowledge in the context of a physics course, these motivations would also be satisfied in a computing science context without physics applications.

The theme of building on prior programming experience as a teacher lies within Intersection 2 ∩ 3, Computing PCK. This theme highlights a few teachers’ experience with teaching computing topics and wanting to expand this capacity. Responses within this intersection focused on the technicalities of computing-based instruction, such as platforms and languages.

Finally, the frequently encountered themes of teaching physics differently, preparing students for postsecondary STEM courses or professions, and teaching a physics course with computation lie within the central Intersection 1 ∩ 2 ∩ 3, Physics-CT Integration PCK. These themes indicate a holistic, interdisciplinary view of what CT integration can accomplish in a physics course.

V. DISCUSSION AND CONCLUSIONS

In the themes discussed in Section IV A, we see a combination of intrinsic motivation and extrinsic motivation. For example, nine teachers framed their interest in learning programming as a response to requests for greater exposure to programming in high school from both their current and former students. This identified need for early exposure to programming represents an extrinsic motivation based on factors outside of the teachers’ classrooms. One teacher shared, “I’ve had a few students who were interested in programming (even participating in competitions), and I wanted to take advantage
of that.” Another teacher focused on former students’ lack of preparation for STEM postsecondary education: “The number of former students that have gone into computer-related majors or computer-related careers is high and yet we offer almost no computer coding classes at any of our district’s comprehensive campuses.” This extrinsic motivation indicates that teachers want to make their high school physics experience relevant for students’ future learning needs.

Evidence of extrinsic motivation was not limited to students’ expressions of interest. Other teachers were similarly motivated by recommendations from STEM professionals. One teacher recalled viewing a webinar from the Department of Energy which encouraged teachers to integrate programming into what they were already doing in the classroom. Another teacher commented, “Every time I have researchers come in to talk with my students, they all say how useful it is to know some coding and that Python is used by a lot of labs these days.”

Although extrinsic motivation related to student interest and professional recommendation was expressed by some teachers, over half (13 out of 24) of teacher responses speak to an intrinsic desire to transform physics education using CT. These teachers reported seeing the physics-relevant benefits of CT as a reason for attending the workshop. For example, four teachers described wanting to integrate CT into their AP Physics courses to improve the quality of their teaching and learning, with one teacher calling this a “re-imagining” of their AP program. Another teacher had been looking for a way to integrate CT into AP Physics for over a decade. Their perception of a gap between students with and without coding experiences had prevented this teacher from integrating CT. They explained how Jupyter notebooks, as a web-based application, would support more equitable access to programming for students with a wide-range of prior experiences: “Jupyter notebooks seem like a way around this - browser-based, prewritten code that could be altered, with more efficient scaffolding.” Jupyter notebooks were critical to our workshop’s focus on Intersection 1 ∩ 2 ∩ 3, Physics-CT Integration PCK. Our workshop approach was responsive to teachers’ motivations to teach physics differently and provide authentic programming experiences for students.

Overall, these teachers entered the workshop already aware of what CT integration could accomplish in their courses and they were eager to realize those benefits. In total, 20 of the 23 teachers’ responses touched on a theme related to Intersection 1 ∩ 2 ∩ 3 in Figure 1. Even before the workshop began, their motivations aligned with our workshop philosophy. They recognized the benefits of CT integration even while 10 of the 20 teachers described wanting to learn foundational computing content and practices (Circle 2). This contrast further illustrates our pathway (dashed arrow in Figure 1), on which they can clearly see the end goal of Intersection 1 ∩ 2 ∩ 3 even while their professional learning begins at Circle 2 [24]. This motivation is critically important for teachers to persist in the process of learning computing concepts and carrying out CT integration in their courses throughout the school year.

We also note the regions of the CTIntegration framework that the teachers’ responses did not address. They did not, for example, report interest in topics at Intersection 1 ∩ 2, physics-computing integration. Although this overlap of physics knowledge and CT knowledge is important in the process of integrating CT into a physics course, the teachers seemed more interested in getting to the pedagogical use of such applications, rather than the applications themselves. It seems that these teachers wanted to learn programming in the context of teaching physics. Most did not mention needing to learn programming, but already envisioned the integration and were less worried about how much Python they needed to learn.

We acknowledge that the teachers in this study self-selected into a summer computer programming workshop and that these results may not be generalizable to all high school physics teachers. Even though these teachers were already interested in integrating CT in physics curriculum and instruction, these observations have important implications for offering professional learning. It seems that, for many teachers, professional learning needs to interweave computing content and practices with pedagogical applications. It is not necessary, for example, to offer every teacher an introduction to a programming language devoid of applications, nor for each teacher to complete a computational physics research project. The pathway of re-novicing that we have established explains both the teachers’ learning process [24] and their motivations for beginning this process.

We have described an online workshop for high school teachers to make progress along a pathway within a CTIntegration framework. This pathway is a re-novicing experience that begins with requisite computing knowledge, progresses through physics applications of computing knowledge, and arrives at physics-CT integration pedagogical content knowledge. We collected teachers’ self-reported motivations for participating in this workshop and used first cycle open concept coding to generate themes in these responses. We then used second cycle provisional coding to map these themes onto teacher professional learning needs. We found that teachers’ self-reported motivations for participating in this workshop focused primarily on the beginning and endpoints of our outlined pathway, with a combination of extrinsic and intrinsic motivational factors. These motivational factors are important considerations in professional learning design and implementation of CT-physics integration in the high school context. Understanding physics teachers’ motivations to learn computing and begin CT integration supports the design of professional learning tailored to their preferences and experiences.

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