How Teachers From Underrepresented Schools Experienced a Blended Professional Development Program on Computer Science and Game Design

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Abstract

Learning computer science (CS) is increasingly becoming a necessary component of K–12 education, but in most cases, teachers do not have either the essential knowledge to teach or a curriculum to follow. In this article, we analyze the outcomes from a yearlong, blended professional development (PD) program to teach teachers game design and coding skills, and we codevelop a middle school curriculum. Using a mixed-methods design, this study presents the findings as we investigate how teachers experienced the PD program. Our findings show that the teachers' level of engagement differed for various reasons, such as challenges related to time, motivation, and interest. We identified a high-engagement group who developed a deep understanding of coding knowledge and engaged in the PD activities more. We also identified a low-engagement group who failed to attend most activities despite mentioning generic interests. We provide an explanation

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why these teachers might have varied in terms of their engagement and offer how "data" can be used to predict engagement levels and as a diagnostic tool (e.g., lacked specificity in explaining CS concepts in reflections). We recommend adding motivational strategies and better tracking and monitoring mechanisms for better engagement and PD design considerations for online and blended learning for teachers.

Introduction

Even though there are new and systematic reform efforts to promote computer science (CS) across all levels in K–12 education (e.g., Australian Curriculum, Assessment, and Reporting Authority, 2015; Bell et al., 2014; Codding et al., 2021; England Department for Education, 2013; Falkner et al., 2018; Mouza et al., 2022; Seehorn, 2011), it is challenging for teachers to integrate CS teaching into their classrooms because the majority of teachers have not been prepared to teach CS. In addition, in most countries and states, there is a lack of CS curriculum that provides engaging learning experiences for students. In most cases, teachers' current level of expertise in CS pedagogy and fundamental knowledge in CS are not sufficient for the successful implementation of any CS content in K–12 classrooms because not many undergraduate teacher education programs offer these opportunities for preservice teachers (Borowczak & Burrows, 2019; Falkner et al., 2018). This is evidenced by the fact that in more than 17 U.S. states, shortages of needed teachers who can effectively teach CS have been reported (U.S. Department of Education, 2015). This situation raises big questions regarding the capacity to teach CS in K–12 schools with not enough well-prepared and trained teachers, a point also raised in the Gallup study by Google in 2015.

The main solution is to provide teachers with professional development (PD) opportunities so that they are equipped with essential skills to teach CS. However, the majority of PD offerings on CS are short in duration and lack continuous and planned support mechanisms (in-person or online; Liu et al., 2011; Mouza et al., 2022). Intense summer institutes are popular but have a small effect on leading teachers to continue their professional learning after timed workshops (Ericson et al., 2007; Ni et al., 2023). Another problem reported in the extant literature is the misalignment among current theories of CS pedagogies, best practices, and CS-specific curricular activities in most PD efforts (Menekse, 2015). Although CS PD opportunities are sporadically available through local regional education service agencies or nationwide (e.g., online workshops) in the United States, the majority are not sustainable, are insufficient in duration, do not focus clearly on teacher-specific CS knowledge, or do not offer sustained support (Menekse, 2015).

There have been negative effects of the COVID-19 pandemic on CS PD opportunities too. Activities that were originally planned to be in-person for teachers were suspended, opportunities for professional learning were limited, and access to technology for PD became a luxury (Delgado, 2021). Concerns about teachers' workload and schedules were raised (Crick et al., 2021). The pandemic forced PD providers and researchers to transition from well-designed PD programs to online options (Brown et al., 2021). For example, in a CS PD program, Goode et al. (2020) transitioned to a virtual PD format by adding an online community for continuous support and participation. Mouza et al. (2022) stated that the pandemic required them to change their face-to-face (FtF) CS PD to virtual, with synchronous summer institutes and dedicated time for teachers to examine resources and sample lesson plans. They achieved positive results in teachers' knowledge and confidence.

Technology and online learning platforms have been opening doors for better, targeted PD options for teachers over the last two decades (National Academies of Sciences, Engineering, and Medicine, 2020), and the pandemic has changed teachers' perceptions of learning through online mediums (Crick et al., 2021). One challenge in online PD work is, however, low completion rates (Perna et al., 2013). Moreover, we have limited evidence on the efficacy of this increasingly prevalent format of PD for teachers teaching CS. Although the growing number of technology-supported modalities are conducive to the wider availability of online PD activities, it is important to evaluate the design features of PD expected to lead to increased student learning in CS (Pollock et al., 2017). To address the lack of opportunities in CS PD, we must find ways to provide practicing teachers with structured, effective PD opportunities and support them to teach CS in K–12 schools so that it leads to changes in teacher knowledge and practices and, eventually, to improvements in student outcomes. The main purpose of this study, therefore, was to investigate teachers' experiences and knowledge gains in a yearlong blended PD program. While aiming to increase our participants' CS knowledge and motivation to teach, we also evaluated our PD program to offer boundaries for success in such work.

Background

Effective Professional Development

Previous research has established that high-quality PD is critical for desirable changes in teacher knowledge and practices and increases in student learning (Penuel et al., 2007). Over the last three decades, high-quality PD has been defined as structured, job-embedded professional learning that includes the following key features (Darling-Hammond et al., 2017; Desimone, 2009; Goode et al., 2014): (a) content focus (PD must address content knowledge [CK], pedagogical knowledge [PK], pedagogical content knowledge [PCK], and knowledge of how students learn); (b) active learning (hands-on, interactive, and contextualized opportunities for teachers to design and try teaching methods to reflect and think deeply); (c) collaboration (learning moments for teachers to work together and to build on their own understanding through sharing and forming a professional learning community [PLC; Dogan & Adams, 2018; Dogan et al., 2016]); (d) duration (PD is spread over a sufficient and sustained time period in an activity); (e) expert support and feedback (a mechanism to scaffold teachers through sharing of expertise about content and effective methods and also by encouraging teachers to reflect and make changes); and (f) uses of model practices (evidence-based samples of lesson plans or teaching observation that provide a clear vision of what model practices look like for teachers). Coherence, or the extent to which PD activities are aligned with state or school reforms and policies, is also important. We took into account these general PD considerations and then specifically worked on CS PD literature.

The research evidence and literature on CS PD (Al-Bow et al., 2009; Borowczak & Burrows, 2019; Davis et al., 2018; Liu et al., 2011; Menekse, 2015; Wolz et al., 2011) are closely aligned with the preceding components of effective PD (e.g., the community-based iterative model; Lloyd & Cochrane, 2006). As Yadav et al. (2013) recommended, CS PD is most effective when professional learning experiences are sustained and enhanced with opportunities for teacher reflection and time to share. To increase its effectiveness, it is essential that it is codeveloped by researchers and district personnel, including teachers, and is closely aligned with schools' goals. Current research evidence also suggests that motivational design principles enhance how teachers interact with other teachers and the material itself (Qian et al., 2018).

Various forms of CS PD have also emerged in the last two decades. These forms range from highly adapted to highly specialized (Koellner & Jacobs, 2016). Faculty-led PD workshops (Cooper et al., 2017; Ericson et al., 2014; Martinez et al., 2016) are supported within the CS community. Moreover, the growing marketplace of PD coaches and providers, new developments and channels for PD experience, and changing expectations of teachers from professional learning opportunities (National Academies of Sciences, Engineering, and Medicine, 2020) have led to the emergence of different, multifaceted models of CS PD, including in-person (FtF), online (asynchronous and synchronous activities), and blended (involving a mix of FtF and online learning) components. A good example of these new approaches is the development of virtual PLC for teachers in which they meet monthly to collaboratively analyze evidence as they teach (McConnell et al. 2013). With increasing interest in using distance learning technologies to support teachers and their knowledge generation and sharing, blended approaches have become promising and preferable among CS researchers and teachers (Yadav et al., 2013). In terms of finance, commitment, flexibility, and scalability, they minimize constraints and risk, and they are found to increase teachers' ability to form social networks with other teachers (Dede et al., 2009).

Motivation Behind Our Professional Development Design

There is a lack of opportunities in teacher education that take preservice teachers to an initial CS teaching certificate (Lang et al., 2013). Teachers earn an initial certificate in another field (i.e., information technologies or business), which in general does not require teachers to take any CS courses (Ericson et al., 2014). Teachers with any of these certifications are allowed to teach any CS course in many U.S. states. Even when professional learning is offered, it suffers from low participation and unbalanced geographical focus (i.e., low-socioeconomic-status parts of states are significantly underprepared for CS efforts).

To address the foregoing challenges, we designed and offered a project built to address the lack of CS curriculum, engaging pedagogy, and professional learning support and opportunities for schools serving high numbers of underserved and underrepresented students (Akcaoglu et al., 2022; Akcaoglu et al., 2023; Hodges et al., 2022). Our work brings together the curriculum (Akcaoglu, 2016) and effective CS PD activities because simply adopting a curriculum without sustained professional learning and support is not sufficient to develop CS pedagogy and knowledge (Goode et al., 2014). Unique to this project, instead of the commonly used block-based software, we used a professional game design engine, Unity 3D, because of the shortcomings of block-based programming and similar "opaque" (i.e., the inner mechanisms are hidden from users) approaches to CS indicated by both researchers and practitioners (Grover & Basu, 2017; Meerbaum-Salant et al., 2011; Repenning, 2017). Unity allows designers to develop games in multiple genres ranging from simple to complex, 2D to 3D, augmented reality to virtual reality. Notably, Unity is free to educational institutions and students and does not require special hardware: It can run on most basic computers.

Our Professional Development Approach

Because of the COVID-19 pandemic, we changed our approach from an FtF PD program to an online activity. The teachers were offered a yearlong PD experience with a blend of asynchronous (discussions and videos) learning activities and synchronous videoconferences during the first 8 months. We based our rationale for changes to the previous studies and literature reviews on transitioning to online CS PD (e.g., Bozkurt et al., 2020; Ferdig et al., 2020). There were virtual badges for motivation and continuation of teachers' efforts (Panisoara et al., 2020); coaching/mentoring (Brown et al., 2021); live collaborative tasks that focused on practice and reflective activities (Jocius et al., 2021); and intense, hands-on activities with coding (Albert et al., 2020). As a research team, we also provided flexibility and chances to skip or get extensions for assignments (Jocius et al., 2021). This kind of emergency also required our interactions to be optional and short in duration (Bozkurt et al., 2020).

Our online activities were followed by in-person (FtF) summer work to promote essential knowledge and skills of teachers regarding CS and game design principles (activities are detailed in Figure 1). All activities were designed following relevant literature summarized in the previous section: (a) a focus on four content areas (software/Unity [or technology knowledge], game design principles and CS-specific concepts [CK], how to teach the curriculum [PK], and how to teach CS [CS-PCK; Yadav & Berges, 2019]; (b) active learning (hands-on experiences with Unity and with the curriculum to analyze, try out, and reflect on the new teaching methods); (c) collaboration (teachers interacted with the experts in synchronous and in-person meetings to improve CK and CS-PCK and also discussed the curriculum and its elements with other teachers by reflecting on how best to teach CS); (d) duration (multiple opportunities for teachers to engage in learning over a year); (e) expert support and feedback (experts [CS and instructional technology professors] facilitated

Figure 1

Professional Development Activities

PD Activity and Phase	Purpose and Content	Focus
Fall PD (September–December 2020). Teachers learned about the basics of working with Unity; completed some initial tasks, reaching a comfortable beginner level through videos; and enhanced their learning in synchronous and asynchronous activities.		
Video-based learning activities	73 main instructional videos (12 hours in total) on Udemy on game design and development in Unity, coding using C#, explanation documents to read, and several downloadable resources (e.g., cheatsheets)	TK, CK
Hangouts	11 weekly 1-hour synchronous sessions in Zoom to provide support and remedial teaching	TK, CK
PLC meetings	In Zoom, four synchronous, 1-hour meetings (4 hours in total), followed by reflections	CS-PCK
Asynchronous activities	In Canvas, (a) three written reflection journals (pre-, mid-, and post-), (b) 12 exit tickets and a written self-assessment, and (c) one social reading activity in Perusall on pair programming	CK, CS-PCK
Winter Institute (January 2021)		
Intensive trainings	In Zoom, 2-day (12 hours in total) synchronous sessions on Unity and motivation (self-efficacy and ARCS)	TK, CK, CS-PCK, PK
Hangouts	Two 6-hour synchronous Zoom sessions to refresh the teachers on the topics covered during Fall PD	CK
Spring PD (February–April 2021)		
Hangouts	Two 45-min synchronous sessions (90 min in total)	TK, CK, CS-PCK
Summer Institute (May 2021)		
Intensive trainings	4-day (24 hours in total) in-person training on Unity (repeating the lessons covered in Udemy) and pedagogical issues (e.g., pair programming); dedicated time and engagement in lesson plan feedback and review cycles	TK, CK, CS-PCK, PK

intensive training in CK and supported group discussions in the form of intentional time for teachers to think about the curriculum, students, and their own practice); and (f) uses of model practices (experts showed the draft curriculum, explained how to teach the curriculum, and provided resources to promote PK and CS-PCK). It should be noted that although designed for our project, the activities described in Figure 1 can be adapted for different content, and therefore we believe that this professional learning framework can be used to facilitate and lead effective PD efforts across other courses or curricula in CS.

Our approach was to engage teachers in quality learning experiences so that they learned CS concepts embedded in game design, Unity software, and pedagogy to successfully teach our curriculum. The blend of asynchronous, synchronous, and FtF activities was offered to create a community of learners (Gray et al., 2016; Jocius et al., 2021; Owston et al., 2008). To increase completion rates, we established visible and complementary links between all three types of activities (Webb et al., 2014) and incorporated activities that establish relevance to teachers' teaching and our curriculum (Hodges, 2004). Moreover, dedicated time and regular opportunities for reflection in asynchronous settings were planned for teachers so that they could "find their voice" in online interactions (Dede et al., 2009; Panisoara et al., 2020).

We used a variety of ways and mechanisms for teachers to navigate learning materials and resources and arranged different channels to communicate with the research team, facilitators, and teachers. All PD activities and documentation were developed to closely match our curriculum, which established relevance and alignment. For teacher satisfaction and motivation, we incorporated badging so that they celebrated their course completion success and accomplishment (Akcaoglu et al., 2022; Jocius et al., 2021), in addition to the payment and other incentives they received for their hourly participation (e.g., Qian et al., 2018).

Purpose and Research Questions

The main purpose of this study was to investigate teachers' experiences and knowledge gains in a yearlong blended PD program. Multiple data points and sources and a longitudinal period to capture the progress of teacher learning were preferred. In addition to our examination of the effect of the program, we opted for a mixed-methods research model to help us not only answer questions about whether the PD program worked but also provide evidence to explain how teachers' backgrounds played a role in their engagement and learning. The following research questions guided our efforts:

1. How were the overall PD engagement, knowledge, and self-efficacy of teachers?
2. What was the teachers' general experience in the PD program?
3. How did participation in the PD program affect teachers' TK, CK, and CS-PCK?

Our research informed us on how blended PD programs on CS should be designed (content, learning approaches, formats of delivery, and motivational strategies) to maximize their effectiveness. In exploring individual teachers' experiences, we hoped to benefit both future teachers who would need to teach CS and those who would be helping those teachers through blended professional learning experiences.

Methods

In this study, we used a mixed-methods approach to evaluate the outcomes of our PD program on our participant teachers. In addition to interviews, discussion posts, and reflections, we collected data about participant demographics, participation, and completion rates from various sources, such as through Canvas Analytics, Udemy Data, and Zoom tracking sheets, over 9 months. As recommended for online and blended PD programs (Dede et al., 2009; Qian et al., 2018), we created metrics as proxies of teachers' engagement in our PD, using analytics from videos and a learning management system.

Participants

Six teachers from four different middle schools in the southeastern United States participated in our PD and research activities. Overall, the teachers had limited experience with coding and game design and did not have any experience with Unity software. More specifically, Teacher D had 5 years of teaching experience and had taught business computer classes for 1 year in the past. She also taught other courses, like English language arts, reading, and mathematics. She did not have previous game design experience or a CS background, nor had she attended any CS or Unity PD activities. Teacher V taught mathematics for 27 years as well as engineering and technology. As for his CS background, he once attended a week-long project (e.g., a crash course) to learn coding. He had no experience with Unity. Teacher R had 17 years of teaching experience, teaching business and information technology (IT) for the last 15 years. She had a limited CS background (e.g., attending some "hour of code" activities). She had never used Unity before. Teacher B had 4 years of teaching experience with an electrical engineering and technology degree. He had worked in IT departments before, and during that time, he did substitute teaching in K–12 schools. He taught mathematics, engineering, and technology. He took some programming classes (some Java and C++) during college, where he had his most extensive coding experience. He offered his students basic programming with Scratch in the past. He did not have any experience with Unity. Teacher M had an early childhood degree and did not have any professional training in CS. She had 11 years of teaching experience and worked as an innovative learning coordinator for her school. Because of her personal interest in technology, she had led student clubs for game design, coding, and robotics in the past. She taught 1 year of Minecraft and used several Code.org activities. Teacher C (who attended only the first part of PD, until the summer institute, before dropping out) was a nurse for 20 years, and this was her second year of teaching business, technology, and computer basics in the classroom. She had some experience with Scratch but did not have any experience with Unity.

Instruments and Data Sources

We collected data throughout a year of PD through various data collection methods and instruments. More specifically, we used interviews, reflections, surveys, discussion posts and responses, analytics data, exit tickets, and knowledge tests (see Table 1). The data, therefore, both represent an extended period of time (i.e., longitudinal) and come from various sources that provide different viewpoints on our research questions. As noted in Table 1, the data were collected at different times and varied in both form and scope.

Data Analysis

Teacher Engagement

To create teachers' engagement profiles, we analyzed the log data, identifying the patterns of teachers' access to and use of PD materials. Because we used different platforms, we were able to make use of data automatically collected in these platforms (e.g., page views, logs), which is an advantage of online PD activities. In addition to the log data, we took the extent to which they were engaged in learning activities synchronously and asynchronously, CS knowledge results, and reported self-efficacy toward coding and teaching coding into account. We also quantified teachers' engagement using Canvas (e.g., discussions, exit tickets, and other writing reflections; time of submission; page views; and the number of posts and responses). In addition, we noted teachers' attendance at the synchronous video conferences (hangouts) and PLC meetings, denoted by the number of occurrences. Teachers' progress in Udemy (the asynchronous video-based Unity learning platform) was measured by the number of video learning modules they completed (three main modules with 73 total videos: Introduction [Videos 1–9], Terminal Game [Videos 10–34], Rocket Game [Videos 35–73]). We triangulated participants' "attendance" with the outcomes from the CS knowledge test and the CS survey to gauge teachers' self-efficacy in teaching and coding after they completed the program (Rich et al., 2021). Combining all these and triangulating them helped us create a measure for each teacher's engagement. We used these proxies to interpret the findings from the interviews and reflections, further triangulating our data and creating boundaries for teacher engagement.

We created two groups: Teachers who participated and engaged in most PD activities (synchronous and asynchronous) were categorized as a high-engagement group, and those who participated and engaged at a lower level or not at all were

Table 1
Instruments and Data Sources

Source/ instrument	*Focus and aim*	*RQ*	*Description*	*PD, When*
Preinterview	TK, CK, CS-PCK	1	Semistructured interviews for establishing baseline data before teachers attended any PD activities, including their CS and Unity background and perceptions	before PD
Postinterview	CK, CS-PCK	2. 3	Semistructured interviews eliciting self-reports of teachers' knowledge and skills regarding CS and Unity	Fall PD and Winter Institute
CS survey	CK, CS-PCK, creating proxies	1-3	Pre- and postsurvey of teacher self-efficacy beliefs about coding and computational thinking (TBaCCT) scale (Rich et al., 2020)	Fall PD
Logs and traces	engage-ment creating proxies	1 1	Metrics and learning analytics data from Udemy (video-based Unity course), Canvas (discussions, reflections, exit tickets), and Zoom hangouts	Fall PD and Spring PD
Reflections	TK, CK, CS-PCK	3	Prompts and questions asking teachers to reflect about software and teaching the material in the beginning (before Fall PD), in the middle, and in the end (after Winter Institute)	Fall PD and Winter Institute
Weekly exit tickets	CK	2,3	Quick self-evaluation of teachers' learning from weekly hangouts	Fall PD
PLC discussions	TK	3	Four asynchronous discussion posts just after synchronous PLC meetings on software, pedagogy, and knowledge that cover multiple weeks of learning (i.e., 1–6 weeks of Fall PD)	Fall PD
Final exit tickets	TK, CK, CS-PCK	1-3	Reflective questions that allow teachers to debrief after each in-person session	Summer Institute
CS knowledge test	CK, creating proxies	3	Final assessment that measures teachers' knowledge of CS, game design, and coding based on content covered during PD	at the end

Note. Our PD focused on CK, TK, PK, and CS-PCK, but PK was not examined in this study. CK = content knowledge. CS = computer science. PCK = pedagogical content knowledge. PD = professional development. PK = pedagogical knowledge. PLC = professional learning community.

categorized as a low-engagement group (for examples using a similar categorization, see Ericson et al., 2014; Qian et al., 2018).

Qualitative Data and Analyses

We collected qualitative data in the form of structured interviews, reflections, and discussions. Because data were collected using structured instruments, we used predetermined categories under each research question to analyze the data. One researcher coded and categorized all data based on the research questions, which generated multiple codes. The first author also analyzed the data by adding their own initial codes and categorizing the codes. Finally, another researcher reviewed the codes to determine if the codes described the teachers' responses adequately. New codes were added as they emerged after the discussion and negotiations among the researchers. After we reached agreement, we synthesized responses to interview questions, reflections, and exit tickets. As noted, we triangulated these data with the engagement data. Therefore, in our further analyses, we created categories based on teachers' background, experience, knowledge, and self-efficacy, and we assigned qualifiers to teachers to represent the unique characteristics that they carry (e.g., "low CS self-efficacy," "mid CS knowledge," "experienced in coding," "some experience in coding," "confident in coding," and "highly motivated").

Findings

Participants' Engagement, Knowledge, and Self-Efficacy

Using three distinct measures, we created a proxy for each teacher and categorized each as high engagement or low engagement, as detailed in Table 2.

Based on Canvas Analytics, Teacher V, Teacher R, and Teacher B had below average participation, even though Teacher B had more posts than others. Teacher C was relatively better at engaging in Canvas and had high on-time submissions. Teacher D and Teacher M had the highest average among all participants. Teachers' participation in hangouts and PLCs in synchronous sessions showed that Teacher R, Teacher B, and Teacher C had below average attendance, whereas Teacher D, Teacher V, and Teacher M joined most of the sessions. Analytics from Udemy demonstrated how many videos the teachers watched and how many modules they completed. Teacher R did not complete any modules, whereas Teacher V, Teacher B, and Teacher C completed only the introduction module, where no coding or game design was involved. Teacher D and Teacher M had the highest completion rates in the group, completing one of the games and starting the second game.

Based on the data in Table 3, Teacher V, Teacher R, Teacher B, and Teacher C were categorized as low engagement, and Teacher D and Teacher M were high engagement. For the qualifiers, using the background interview, the CS knowledge test, and the self-efficacy survey results, we also described the participants as summarized in Table 3.

As expected, our data indicated that the teachers' engagement in the PD activities and knowledge and self-efficacy developments were varied. Although there was variance among different types of data, using attendance and log data helped us clarify and identify different engagement profiles of teachers, which we were then able to triangulate with data on teachers' CS backgrounds.

Teachers' General Experiences

Our PD was structured mainly around asynchronous activities (Udemy videos, Canvas discussions) coupled with synchronous sessions (weekly videoconferences). The low-engagement group realized the benefits of these activities. Teacher B pointed out the advantage of having self-paced and practical activities: "I enjoyed being more in control of my learning." He added that "being able to review the lesson . . . it's good and that's what matters." He also thought the other activities surrounding the video modules (creating games simultaneously and engaging in reflections) were helpful:

Table 2
Proxies and Categories

	Canvas Analytics				*Zoom*		*CS survey (efficacy) postsurvey*				
	On time (%)	*Page views*	*Posts*	*Module completion*	*Hang-outs*	*PLC*	*Udemy module*	*Post CS test*	*Value belief*	*teaching coding*	*confidence in coding*
Teacher D	81	304	17	15	12	4	36	78	4.2	4.9	5.5
Teacher V	50	186	5	8	13	4	12	35	4.4	5.1	4.5
Teacher R	50	62	2	4	7	3	0	NA	4.2	3.6	2.4
Teacher B	58	93	16	8	5	4	14	68	4.5	5.1	4.8
Teacher M	96	343	31	14	10	4	41	73	4.4	4.6	4
Teacher C	86	142	28	12	7	4	17	NA	NA	NA	NA
Average	71	188	16.6	10/25	9/15	3.8/4	20/73	64/100	4.3/6	4.7/6	4.2/6

Note. CS = computer science. NA = not available. PLC = professional learning community.

Table 3
Categories and Qualifiers for Participants

Engagement/participant	*Qualifiers*
Low	
Teacher V	some experience in coding, low CS knowledge
Teacher R	low self-efficacy in coding and teaching coding
Teacher B	some experience in coding, moderate CS knowledge
Teacher C	limited experience in coding
High	
Teacher D	highly motivated and confident in coding and in teaching coding
Teacher M	highly motivated to learn coding, some experience and CS knowledge

Note. CS = computer science.

> You had to basically apply what you know, not just watching the videos and type in the code. You have to type the knowledge that was gaining. You have to think what could I use . . . a better understanding of what . . . so it allows you to think how you would all your students may react so that's one thing that I do like about the modules.

Teacher V highlighted the benefit of the weekly videoconferences due to their social and collaborative nature when he said we "get caught up or discuss the problem that we haven't had a chance."

Other activities in PD that appeared to be important for the low-engagement group were hangouts and expert support. Teacher B enjoyed hangouts because of "being able to tackle with and beyond being able to go back through the program and just getting that extra feedback." He was aware that expert support was available for him:

> If I get stuck in . . . aware of, see where I'm going wrong. No. You all are here to help me. Get through that obstacle. So, and [other teachers] also know just suggestions that you know the other teachers give as well, too, because you know they're going through it, so they can see the struggle.

Teacher V saw expert support as a mediator to his learning: "[Hangouts are] helpful. [Experts] helped out a lot. And then the hangouts . . . the reinforcement of the concepts, we learned in the video."

The low-engagement group had two important points that can be identified as needed improvements. Two participants who had low CS knowledge (and also had some experience in coding) at the end of the PD activities believed that they needed more FtF time and training. Teacher B said, "The biggest thing is . . . the atmosphere that we're working with now with the environment . . . hands-on is great." Teacher V clearly explained that he needed more in-person opportunities: "I can see if you know I could raise my hand and ask a question at that point in time."

Another important finding was that teachers in the low-engagement group needed peer teachers to get more help and support at their schools. Teacher C reflected on her experience with Teacher M (who was in the high-engagement group and working at the same school) as a good resource at the school, as she was also in the project. She valued Teacher M's experience, as evidenced by their discussion on how to teach the curriculum. Similarly, Teacher V believed that Teacher D (who was in the high-engagement group), "who does that work in a school . . . she's pretty fluent with this [coding] . . . because that she's done in the past, and she's pretty farther along than I am with it, so if I need something I go to her."

Lack of confidence and knowledge also appeared as important from the interviews and exit tickets. Teacher V thought, "As far as my confidence of teaching it right now [very close to the end of the program] I will have to go back over again to feel you know more confident for us trying to teach the skills to students." From the data collected in three different occasions, Teacher C talked through the same point. From an earlier exit ticket, she "didn't understand code but I have realized by re-watching the videos, I can better understand." In one of the later exit tickets, she felt the content was "still very challenging for me but with repetition it gets a little easier." At the end of the PD, she said, "Just the coding, in general, just doesn't make sense to me. I mean, it's just so boring to me. The more I see it, the more I can mimic it. But to truly understand it, I'm not gonna say I understand it."

As for the high-engagement group, Teacher D and Teacher M completed more than half of the video modules. They had some difficulties regarding learning from the videos. Teacher M was motivated to learn, and she found the video modules confusing:

> The Udemy courses are good, but move way faster than me. It is hard to keep up. I feel like I miss information even when I rewind. The teachers in the modules talk really fast . . . and have unnecessary information that can be confusing. Some of the last modules were extremely challenging to me.

Both high-engagement participants took advantage of the time that they came together and of expert support in synchronous hangouts. Teacher D believed that the combination of learning activities functioned well. "I also enjoy when we came together, I did talk more with the other teachers when we had our training in January. . . . The videos were excellent. But the hangout as well." Teacher M also highlighted the importance of having someone to work with during PD. From the interview transcript, Teacher D enjoyed expert support from the researchers, and she thought "[the researchers] did not leave us out there by ourselves. If we need it, we could always do is reach out." Teacher M also reiterated the value of expert support and found it helpful: "I feel like I will benefit from remediation [through hangouts]." Teacher D was confident, and Teacher M was a motivated teacher. They believed that after learning coding and CS, they had the confidence and motivation to implement what they had learned in their own classrooms: They said, "I feel confident I can implement the materials the way the team has planned for them to be implemented after completing the course" (Teacher M, mid-program); "Knowing that I will be responsible for delivering this instruction motivates me to dig deep and try to really understand it. I want to provide quality instruction when I teach this program" (Teacher M, end of program); "I do believe the project along with me inspiring them will boost student confidence to reach beyond their norm and embrace the difference" (Teacher D, mid-program); and

> What has motivated me throughout the course is the fact I am doing something that I once loved to do and moved away from and also the fact I am learning it to teach it to my students. I still feel excited about the project as I did in the beginning. (Teacher D)

All in all, there were some commonalities and differences between the high-engagement and the low-engagement groups. For both, the hangouts and the expert support were useful for remediation and learning. On the other hand, the two groups differed in terms of confidence: The low-engagement group felt less competent in coding and teaching coding. The low-engagement group did not complete most of the asynchronous activities and therefore could not speak to the video modules, compared to the insightful notes from the high-engagement group. The low-engagement group asked for more FtF sessions and wanted to work with someone to teach the curriculum, which is an important finding not mentioned by the teachers (with whom they worked at the same school) in the high-engagement group. Given that CS backgrounds were mostly low for all participants, one key difference separating the two groups was that the high-engagement teachers were more motivated (due to past experience) than the low-engagement teachers, which kept them going in the face of difficulties.

As we discuss in later sections, another key difference was how the high-engagement group was able to develop specific knowledge (as noted in their reflections) and the confidence to tackle problems. The low-engagement group never reached that confidence, and their reflections were mostly on general topics. Although they benefited from different PD activities, we believe it was this motivation that kept the high-engagement group on task during the asynchronous activities, which require more learner self-regulation and control.

Impact on TK, CK, and CS-PCK

Participants reported that there were changes in their knowledge and skills in all four domains as a result of our PD. Our first finding was that both groups learned the basics of Unity as software (TK) regardless of their engagement level based on the exit tickets, the postinterviews, and the CS test. The low-engagement group learned how to download the file, set the preferences in Visual Studio, write some code in Visual Studio, and attach the code to the characters in Unity. Teacher B reflected further, "As far as my skills as Unity, as a whole, [it] has improved. As far as being able to work the actual programming other system and just understanding how to tie everything together with decoding."

Adding to these skills, the high-engagement group reported more specific skills they learned. For example, they noted that they learned "how to use terminal. WriteLine" or, as in the case of Teacher M, that "using the inspector made creating the design much easier," which is a very specific note about designing games in Unity. The more teachers were engaged in the learning content, the more they discovered about Unity. The result from the CS test also supported the findings from our qualitative analysis. Both groups received full points for the questions related to TK. For example, when we asked where in Unity print("Hello world!") would show, they all gave the correct answer: the console.

As for CK and CS-PCK, the difference between high-engagement and low-engagement groups was present in their understanding of the CS concepts during the online video-based courses. Looking at the module reflections, we were able to identify the key differences between the two groups in the amount of detail they provided regarding the content and concepts they learned. For example, one of the high-engagement teachers, Teacher M, was very specific in her discussion of the topics covered in each module and commented on issues related to coding (e.g., "I learned how to add public string above start to allow changes in Unity. Also, how to use + to add variables and "" for space") and to Unity-related things she had learned (e.g., "I learned you can change multiple pieces of the same code by highlighting a piece of code and clicking Control-R"). Similarly, Teacher D had coding-related comments ("One thing I learned was the use of switches. I like the switches a little better than the if else statements. It helps to keep the coding cleaner and more readable") and Unity-related notes ("I learned that source tree is my new best friend. I do not understand why drawing is so difficult for me but I have learned to use the inspector and scale by numbers instead"). In contrast to the high-engagement teachers, as expected, low-engagement teachers mentioned only generic, and often vague, concepts or topics. For example, Teacher V indicated, "I learned how to use debug to see hidden variables today," which lacks specificity and does not point to a specific learned concept. Similarly, instead of focusing on specific opportunities or challenges, Teacher B noted, "I have learned the basic steps of creating code and running code with the game Terminal Hacker." On the basis of these data, we can point out two important conclusions: (a) Variance among participants in their engagement with the learning content is to be expected and (b) PD participants' engagement can be interpreted by the level of specificity they report back in their discussions.

When we juxtaposed the results from the CS test and the findings from our qualitative analysis, we also found a consistent relationship between the test and the self-reports. For instance, Teacher V (low engagement, low CS knowledge) scored 35/100 on the CS test, and his responses to the open-ended questions were limited in scope. Even though he had some experience in other coding systems and languages, his CK was measured as low. This pattern was also evident in Teacher B, who was also in the low-engagement group. His responses neither included detailed CS terminology nor had much elaboration of CS, coding, or any relevant game design concepts.

For the high-engagement group, the trend was in the other direction. For example, Teacher D shared, "One thing I learned was how to create my win screen using ascii art. I also learned how to add another level by copying my previous code and pasting it where needed; ensuring to change the level to reflect the new level." Exploring her responses to the test more deeply demonstrated that she scored 78/100. When she was asked to write a conditional statement in C# and elaborate given code, she provided detailed and correct explanations. From the interviews and the reflections, we observed that CS-PCK (how to teach CS) and PK (how to teach the project curriculum) were elaborated on together by the teachers. Similar differences were also found between the high- and low-engagement participants in their description of CS-PCK. The highly engaged group pointed to detailed and specific issues. For example, Teacher M noted,

> After the meeting, I better understand why we would use an array and switch in our codes. I also learned the importance of mapping out the solution to the challenge in plain English. I think this will be an important part of redelivering this information to students.

Here we see that she spoke to the importance of pseudo-code as a teaching strategy and tool, something she learned directly during our PD workshops.

On the other hand, the low-engagement group seemed to touch only upon generic topics, making it hard to gauge if a real understanding of CS-PCK was there. For example, Teacher R noted, "I would give my students a learning target at the beginning of the lesson and have them respond to it, along with an assessment to measure their level of understanding and mastery." Similarly, Teacher V pointed to a very generic teaching tool, videos. As can be seen from this quote, this shows a very generic understanding of the topic compared to the participants in the high-engagement group.

To sum up, both groups gained relevant knowledge and skills through our blended PD. However, our findings point to the difference in specificity in terms of engagement level of the teachers. Highly engaged teachers showed their understanding by focusing on and pointing out specific issues or topics, whereas low-engagement teachers often brought up general topics or concepts.

Discussion

Our PD program focused on equipping CS teachers with the necessary skills and knowledge, known as CK and CS-PCK, as highlighted by Yadav and Korb (2012) and Yadav et al. (2016). In addition, we incorporated effective PD features outlined by Desimone (2009) that were relevant to the challenges brought about by the pandemic, including increased online components, as discussed by Goode et al. (2020) and Mouza et al. (2022), as well as CS-specific PD components, as suggested by Menekse (2015). Our findings show that the teachers benefited from our targeted content through various activities at varying levels. We identified ways to gauge engagement, including taking into account the level of detail participants used in their reflections and interviews (e.g., superficially used CS concepts during the interviews and the reflections).

Unique to this study was that creating proxies from the metrics provided individual usage patterns to identify engagement patterns. Previous CS-related PD (with online components) studies (e.g., Martinez et al., 2016) reported their findings based on an overall picture of teachers' engagement by assuming that all teachers were actively and fully engaged in PD. However, a closer examination is needed to differentiate teachers who are engaged from those who are not, especially for PD having online activities. We used these patterns to understand how teachers with different levels of engagement experienced our PD.

The same materials and activities in blended PD programs might not create similar effects for every teacher. Their engagement and use may depend on their background, needs, interests, and/or motivation. In our study, interestingly, limited participation and low interest were observed for the teachers with some experience in coding and more teaching experience. On the other hand, the teachers with no or low CS experience showed interest and were engaged more in the PD activities. These findings echo the findings in some previous studies (i.e., Qian et al., 2018): Experienced teachers with CS backgrounds believe that they do not need PD, but novice teachers (for CS) can use and take advantage of PD materials more. And motivation to learn at a PD might be more dependent on factors other than background knowledge alone.

Another surprising finding was that the teachers who attended CS and/or coding trainings previously and took courses before our PD did not do well in terms of engagement and knowledge gains. It is possible that their previous experiences might not have clearly related to the content in our PD. In fact, in a recent study, we found (Akcaoglu et al., 2023) that interest development, and specifically affective aspects of it, was key to understanding the level of engagement the teachers showed throughout the PD program (Hidi & Renninger, 2006). Therefore prior experience should not be equated to skill or knowledge, and PD providers should assess these and determine activity structures tailored for individual teachers. As we noted in this article, in addition to the surveys and tests, teacher reflections (i.e., the lack of specificity) can be used as a benchmark for this.

Our results also indicate that the modality of PD, video-based learning activities, and materials might have different impacts on teachers' engagement. The high-engagement group had feedback to improve the video modules. Because they were motivated, they continued watching the videos and attending the activities irrespective of the improvements needed. However, the low-engagement group had lower video views. The length and number of the video modules might have adversely affected their engagement because the videos are the primary source of learning CS. From cross-linking our data, we realized that the low-engagement group asked for more FtF sessions. Their learning preferences might not be well aligned with the video modules we offered, which require self-pacing and self-directed learning.

Regarding the videos in Udemy (or asynchronous video-based modules in general), based on the feedback from our participants, more creative and interactive elements should be incorporated to improve teachers' engagement and learning. Prerecorded videos were used in this study as a part of our PD design. However, assigning videos with no interaction or follow-up might not affect teacher learning (Means et al., 2009; D. Zhang et al., 2006). As a remedy, our team produced lecture-capture videos with specific case examples related to coding in Unity. Our own production videos received good feedback from the teachers (from informal communications) because the content better aligned with the curriculum, and the presenter was a familiar person for the teachers who organized all weekly hangouts. Therefore it is critically important to address teachers' previous experience, needs, and preparedness to learn and teach CS when designing blended PD experiences. Teachers with some coding experience, teachers with confidence and motivation, and teachers who have low self-efficacy might need different PD resources and activities. To improve our PD, we need to go beyond that and prepare interactive video materials with quizzes, immediate feedback, and open-ended questions, which is an effective way to improve engagement and enhance learning (B. Zhang, 2020) and satisfaction (Merkt et al., 2011). Automated systems with artificial intelligence (Price et al., 2017) and adaptive software (Cheng et al., 2021) can also remedy this issue.

Although all participating teachers liked our PD design (e.g., FtF institute, hangouts, and expert support), four teachers were low-engagement users who failed to use the video modules. Most importantly, when closely examining the high-engagement group, we realized that these two teachers had intrinsic motivation. From a perspective of motivation, our project provided incentives for attending PD events and completing PD activities. Financial support seemed to increase engagement somewhat. However, we believe that monetary PD support was an extrinsic reinforcement that brought only short-term motivation to teachers and did not affect their intrinsic motivation and dedication to learning (Keller & Suzuki, 2004). As lessons learned from this study, designing PD activities also requires careful planning of motivating factors based on teachers' backgrounds and creating focused engagement activities as a priority (Creemers et al., 2012; Hodges, 2004). More and targeted motivational strategies to promote intrinsic motivation (either FtF, synchronous, and asynchronous) can be added to blended PD programs as regular activities.

One additional note has to be made with regard to the transition to online CS PD. The program achieved some positive results despite the complexities and uncertainties of the pandemic era. The increased focus on individual teachers' learning through one-to-one mentoring support (as also evidenced in Brown et al., 2021; Goode et al., 2020) might be one reason behind this achievement. Moreover, the online community we created for the transition was helpful for both groups of teachers. Previous CS PD studies produced similar results (Goode et al., 2020; Mouza et al., 2022), showing that collaboration and being together in the same virtual environment at the same time are conducive to professional learning (Ni et al., 2023). Even though we didn't specifically ask teachers to talk about the effect of the pandemic, time constraints, and other teacher-related factors (such as scheduling issues, sickness, and overload), these could be influential on teachers' attendance, especially for the low-engagement group. This was parallel with other CS PD studies conducted during the pandemic stating that teachers encountered emotional stances and workloads (Jocius et al., 2021; Mouza et al., 2022).

As Sentance and Csizmadia (2017) suggested, another improvement to be made for a better PD design that boosts teachers' motivation might be credentials or recognitions offered to the completers of the PD. A professional recognition or a badge that carries PD credits can influence teachers' motivation and interest in higher engagement and increased CS knowledge and pedagogy. It is also important as it is related to relevance and satisfaction (Keller, 1999). Digital badges can also help teachers stay motivated and on track with their learning (Gibson et al., 2015). Indeed, we tried Badgr (an automated app awarding badges) and integrated it into Canvas. When teachers completed an asynchronous activity in Canvas, they could be awarded a badge automatically, customized by the team. The teachers and we were able to track and describe progress and accomplishments on the leaderboard in Canvas. However, for the Udemy video modules and other synchronous activities, we did not try a badge-awarding method. Further practices of using digital badges with a planned flow could improve engagement and motivation. Future research is also needed to explore how digital badging affects teachers' engagement in blended and online PD.

When we examined the changes in teachers' knowledge, we found sharp differences in terms of teachers' understanding of CS concepts and the level of specificity in their elaborations. This finding is also supported by previous research in that active participants did not have any issues explaining CS-related topics when asked (Qian et al., 2018; Siy et al., 2017). Teachers who got better and more experience from PD provided "original and in-depth explanations of coding concepts," but "other teachers superficially introduced CK" (Martinez et al., 2016, p. 77). As teachers were more engaged in content, they were more likely to grasp the relevant ideas. Future research is needed to see if low engagement in a PD program causes teachers not to understand CS concepts deeply. Examining what challenges they might have in well-planned PD activities in less active groups would also carry some merit. In addition, one cross-connection from our analysis reveals that a relatively small number of FtF activities might result in low engagement for some teachers who need more in-person learning time. Thus one question is what to do with these teachers. Do/should we put low-engagement teachers in yearlong PD programs into a remedial group who will take a different PD? Or should these teachers be dropped from PD programs? Maybe new research studies need to ask if blended PD opportunities should be personalized or differentiated in terms of participants' backgrounds.

Limitations

Our study was a yearlong examination of teachers' experiences through ongoing and multistaged data collection methods. We recognize that our study has some limitations. First, except for the CS test, some data sources were based on the self-reports of the teachers. For some participants, their self-reported knowledge in the interviews was different from the direct assessment of their knowledge. Self-reported data may have reliability issues because teachers may be apt to overreport certain behaviors as they relate to their learning (Porter et al., 1993) and may find it hard to remember previous learning accurately (Yu, 2014) in long-duration programs. In our study, however, because we had additional "activity" data, we could triangulate self-report data and therefore identify self-report biases. Second, we used the analytics and the post measurements as proxies to categorize teachers' engagement levels. Even though we did our best to determine their levels accurately, because it was a comprehensive program, teachers' engagement levels might decrease or increase at different times during our PD. We could not consider this and just provided a general picture of the engagement profile. Finally, naturally, our sample was drawn from our geographical region and might carry biases that are embedded in our context and teachers' backgrounds and schools. We believe, however, that our results should be able to inform similar populations where teachers are overburdened and have limited time for PD, which is a likely reality for teachers around the world.

Conclusions

Low CK of teachers has been seen as one of the key reasons for attrition and dropout from CS at precollegiate levels (Metzler & Woessmann, 2012). Middle school is a critical milestone that affects students' career choices (National Research Council, 2005). It is important to address this obvious problem in middle school before it starts becoming a major issue by equipping teachers with essential knowledge and resources. There are yearlong and other effective CS-specific PD programs offered for teachers (i.e., Siy et al., 2017). However, we need to discuss whether the extent to which and the way teachers are engaged are more important than the design of PD itself. Regardless of the format of PD, we need to improve teachers' CK and CS-PCK by creating engaging and interactive PD opportunities. Our blended PD approach provided engaging opportunities for teachers with a focus on essential professional learning domains to teach CS, game design, and coding. Enhanced with synchronous and asynchronous activities, the participating teachers were supported through various mechanisms. Our general PD design followed the structures suggested by extant PD literature, with a focus on content; inclusion of hands-on, interactive, and contextualized learning opportunities; opportunities for collaboration among participants and experts; long duration; frequent expert support and feedback; and content design matching both best practices and the curriculum to be taught in the classrooms.

Given that retention is a major issue in online PDs (Freitas et al., 2015), our design hybrid overcame this problem, allowing us to retain all teachers in this yearlong program during the COVID-19 pandemic (2020–2021). However, participation and engagement (and learning levels) varied across participants: Four participants were in the low-engagement category, which affected their CS-relevant knowledge and skills gain. This was a key finding regarding our PD design itself. Understanding high engagement was important to set norms in professional learning that might translate into effective CS teaching and curriculum implementation. Identifying the patterns in low engagement helped us identify barriers, issues, and improvements that need to be addressed to improve PD impact.

We also overcame the misalignment issue, a challenge common to online PD offerings (Creemers et al., 2012), by codeveloping the curriculum with the teachers based on Georgia state standards. Our PD also incorporated activities that motivate and encourage teachers by establishing relevance to their teaching and curriculum (Hodges, 2004). Therefore it was our expectation that the teachers would be involved in all aspects of our blended PD activities. In part, we have accomplished our goals, but issues regarding motivation and self-efficacy in the context of PD need to be reconsidered.

In addition to using a variety of methods, the timing and occasions of measurements were considered. Most data in PD programs are collected immediately after the program concludes. However, because teachers learn, make sense of, and transfer their learning at every stage of a longitudinal PD program and improve and practice what they learn over time, we collected data over time as well. We believe that the more data sources we have and the more varied the timing of the measurements is, the more likely we are to create a clear, complete picture of the extent of teacher learning as they are engaged in synchronous and asynchronous professional learning activities. This diversified approach offers higher degrees of validity to teachers' actual learning and experience.

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