Lessons in Adaptation: A Five-Year Design Analysis of Culturally Responsive Computer Science PD for Elementary Teachers

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Abstract: This study examines the evolution of a professional development (PD) program over a 5-year period designed to enhance computer science (CS) education in elementary schools. Despite growing emphasis on CS in K-12 education, elementary teachers often lack resources and training. Our project addressed this gap by offering an annual summer PD Institute (2020 to 2024), aimed to equip K-5 teachers with content and pedagogical knowledge needed to integrate CS into their curriculum. The overarching intention of the program is to increase CS opportunities in elementary schools, with a focus on engaging female students and those from underrepresented backgrounds. Utilizing the framework of Technological Pedagogical Content Knowledge (TPACK), the PD design was iteratively refined based on teacher feedback and artifact analysis. We conducted a retrospective, qualitative analysis to identify core PD characteristics and their evolution. Our findings reveal how PD content evolved across dimensions of the TPACK framework, with the fifth year achieving a balanced distribution of components. This study contributes to understanding effective design principles for elementary CS teacher PD and highlights the importance of researcher-teacher partnerships in building a community of elementary CS educators.

Keywords: TPACK, Elementary grade, In-service teachers, Professional Development

Introduction

Worldwide, there is a growing emphasis on cultivating computer science (CS) literate youth to foster active citizenship, enhance employability, and tackle social inequity (Vegas et al., 2021). Consequently, it is crucial to equip K-12 educators with the tools to deliver comprehensive CS education to all students from PreK through 12th grade. Across the United States, various local, state, and national CS education initiatives have been introduced (Code.org, 2023). However, greater emphasis was placed on middle and high school teachers leaving elementary teachers largely underserved (Mason & Rich, 2019). A recent national survey of CS teachers in the United States reports that elementary teachers display the lowest confidence in teaching CS (Ni et al., 2023) and are less likely to have received CS training (Koshy et al., 2021). Early exposure to CS education fosters interest, particularly among underserved populations (Vegas et al., 2021), highlighting the critical need to focus on elementary teachers' CS training.

One major barrier is the lack of grade appropriate CS materials with PD (Liao et al., 2024). While resources have been devoted to the development of curricula for high school students (e.g., Exploring Computer Science, 2022), such work is only beginning to emerge for younger students (Code.org, 2024). In the US, elementary teachers are expected to be generalists who can teach all subjects (Holincheck & Galanti, 2023). This implies that incorporating CS into elementary grades is often left to the teacher's discretion that is highly influenced by their beliefs, knowledge, and self-efficacy (Mason & Rich, 2019).

The key to effective CS integration at the elementary level lies in contextualized teacher supports. This approach to PD should address local educational requirements, be tailored to specific grade levels, provide a range of resources for diverse classrooms, and enable K-5 educators to confidently embed CS principles within their existing curriculum (Jocius et al., 2024). To address these challenges, we initiated a multi-year research-practice partnership project in the Mid-Atlantic region. Our goal was to equip K-5 teachers and education leaders (e.g., teachers on special assignments, instructional coaches, librarians) with the knowledge and tools needed to integrate CS into their instruction utilizing culturally responsive pedagogy shown to broaden participation in computing The project aimed to increase CS education opportunities in elementary schools, particularly focusing on exposing female students and those from historically underrepresented backgrounds to CS at a young age. We sought to achieve this by nurturing an elementary teacher community that developed contextual and grade-appropriate CS instructional materials that are culturally relevant to their students. The project model consisted of a summer PD institute, followed by ongoing support throughout the academic year.

The summer PD Institute served as the primary venue for teachers to connect and expand the network of professional CS educators in the state, making a successful PD program crucial to the project. We believed that a high-quality PD experience would encourage teachers to incorporate CS instruction into their teaching, motivate them to return in subsequent years to enhance their professional education, and inspire them to become more involved in the cause—ultimately becoming part of the infrastructure that facilitates culturally relevant CS instruction. With this vision, we offered five years of PD, continuously adapting and refining our model to better serve our teachers.

As we conclude the project, we conducted a retrospective analysis of our PD design to understand how we refined the program to better support teachers each year. Drawing on practices from design-based research (DBR) (Cobb et al., 2003), we explored how our theoretical design of the PD—stemming from the TPACK framework (Mishra & Koehler, 2006) —and our implementations converged to provide more contextually relevant and meaningful PD for teachers. We hypothesized that such PD would not only improve teacher knowledge and cultivate culturally responsive educators capable of reaching female and underrepresented students but also develop a repository of classroom-tested, interdisciplinary CT-integrated lessons and materials. This repository would be valuable to teachers across various contexts in the state and further strengthen the infrastructure/capacity for elementary CS instruction in the state. The following questions guided our inquiry:

1. What were the core characteristics of PD design across the five years?
2. How did PD design evolve over the years to become more contextually relevant for teachers?

Theoretical framework of Culturally Responsive CS PD

The design of the PD was based on the TPACK-CS/CT framework (Authors, 2017; accepted), which provides a conceptualization of TPACK in relation to CS and computational thinking (CT). This framework describes educators' capacity to integrate CS/CT concepts, tools, and methods with subject matter and teaching strategies to achieve meaningful learning outcomes in specific educational settings. Here, CT extends beyond knowledge of computers to capture broad skills of programming that are applicable to other subject areas (Wing, 2006). A more recent conceptualization of the framework offers clearer definitions of CS/CT integrated instruction, emphasizing equity and contextual factors (Authors, accepted). In this framework:

- Content knowledge (CK) refers to knowledge of both CS and CT and traditional disciplines such as mathematics and science.
- Pedagogical knowledge (PK) encompasses general pedagogical knowledge (e.g., classroom management, active instruction models, group work) and CS-specific teaching knowledge (e.g., pair programming, CS unplugged activities).
- Technology knowledge (TK) includes knowledge of digital and non-digital technologies, as well as CS-specific technologies like programming tools (e.g., Scratch) and robotics (e.g., Bee-Bots).
- TPACK represents the synthesized body of knowledge that enables teachers to bring together the three knowledge bases of content, pedagogy, and technology to promote effective CS/CT content-integrated instruction.

- Context refers to broader systems influencing teachers' work, which can either support or impede their efforts towards CS/CT integration. In this study, we interpreted context to include state teaching standards and the need for diverse instructional resources tailored to local school needs.
- Equitable pedagogies encompass asset-based practices that foster learning and empower students as agents of social change. In this study, we implemented this concept through culturally responsive pedagogy (Madkins et al., 2020). To become culturally responsive, teachers must ensure their teaching practices and content reflect, sustain, and build upon their students' and communities' identities, assets, histories, and contemporary realities (Gay, 2010). With this goal in mind, we designed the PD to train teachers in understanding culture, addressing equity issues in computer science, and implementing culturally responsive CS teaching methods.

Design-based research

Studies have shown that using a design-based research (DBR) methodology, that gives teachers more control and involvement in shaping their learning experiences, can yield multiple benefits. Firstly, it can enhance the meaningfulness and usefulness of teachers' PD (Zinger et al., 2017). Additionally, it can provide reusable design principles for future technology integration PD (Wang et al., 2014).

A DBR approach aims to develop theory about learning and the mediators of learning in naturalistic settings through iterative design and feedback from real world partners and experiences (Cobb et al., 2003; Wang et al., 2014). The DBR approach pays systematic attention to the context of intervention and draws from evidence of measures of learning to inform each cycle. From a theoretical viewpoint, the intersection of DBR and PD presents a valuable opportunity to examine the potential effects on teachers' acquisition of TPACK (Zinger et al., 2017). Given the context of our study that involved researchers working closely with teachers and teacher leaders, using survey and interview data to refine the PD over the years, and working closely with teachers during classroom implementation to understand practical application, we were appropriately situated to conduct a retrospective analysis of our project to explore PD evolution and design principles.

Study context

This research is an NSF funded initiative between [university name blinded for review] and [State department of education blinded for review] (e.g., Authors, 2022) to enhance CS/CT instruction in elementary grades through an equity-centered partnership, featuring collaborative design cycles between teachers and researchers. The program ran from Fall 2020 to Summer 2024 and was structured around two components: a face-to-face, week-long Summer PD Institute for teachers and follow-up classroom implementation support including virtual PD sessions, one-on-one consultations, and implementation support (Authors, 2022). Participation in the institute culminated with lesson design sessions that integrated CT with disciplinary content and CRP in K-5 instruction. During the academic year, teachers worked with the research team to refine and implement their lessons and collect student data.

The summer PD was designed using TPACK-CS/CT and CRP and aimed to provide teachers with a balance of CS knowledge, culturally responsive CS teaching, and strategies for content integration through hands-on and active learning strategies (Authors, 2023). Each year, the research team, lead evaluator, and some teacher leaders met regularly to develop relevant instructional materials, analyze previous data collected, and discuss key issues concerning implementation. A secure online repository housed all materials and meeting notes, providing comprehensive data for an in-depth reflective analysis of the PD.

Data collection and analysis

This study uses the data stored in the online drive from the last five years. Data includes PD planning documents, teacher survey and interview feedback from the annual summer PD institutes, yearly reports from the project evaluator, and team members' published works.

To visualize the evolution of the professional development (PD) program, a researcher recreated the schedules for all five years on a virtual whiteboard using Canva.com. The main topics of each day's sessions were listed and mapped horizontally according to their duration, with the length of each block representing the session's time allocation (Figure 1).

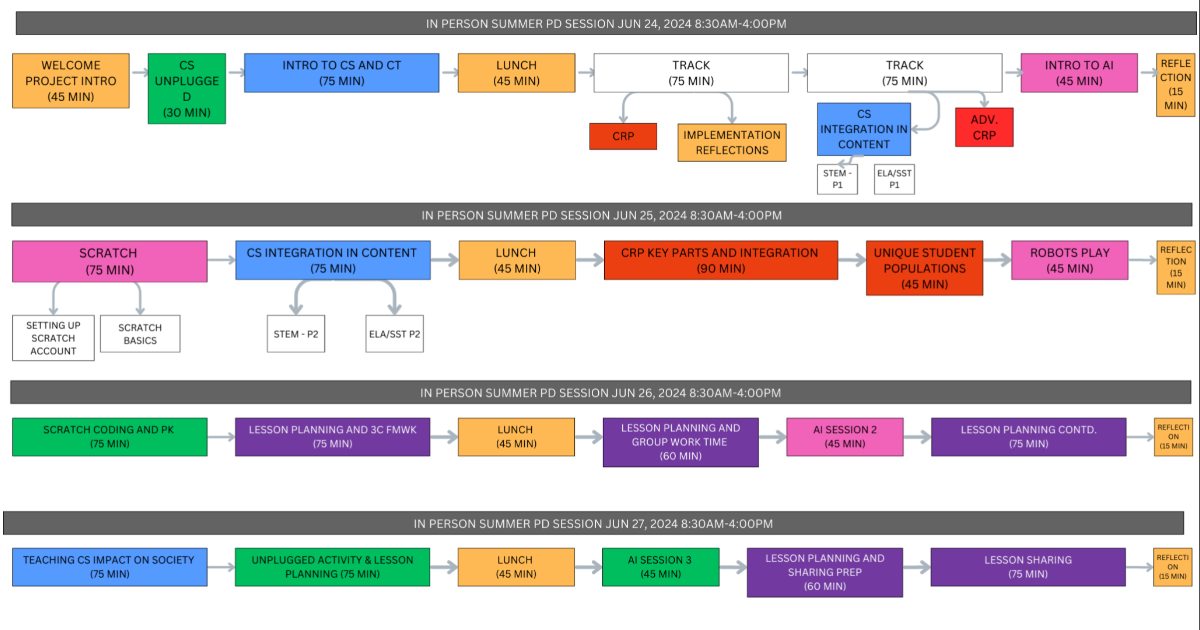

Figure 1: Visual representation of summer PD in 2024.

Figure 1, illustrates the PD schedule from the most recent implementation, showcasing the topics covered each day. The session blocks were then color-coded based on the TPACK-CS/CT framework to highlight how its dimensions were implemented. Blue represents CK, green represents PK, pink represents TK, red represents CRP, yellow represents context, and purple represents the integration of all dimensions. This visual aid proved invaluable for understanding the distribution of content across the years. Lastly, we tallied the duration of each session and created a stacked bar chart to display the amount of time dedicated to various dimensions of the program over five years (Figure 2).

Next, the insights from the survey data, the teacher interview data, and the evaluation reports were added to the virtual whiteboard to track the research team's insights and recommended changes throughout the years. The recommendations were mapped onto the following year's PD design to see which ones were implemented and which ones were not. Throughout the creation of the whiteboard, other members of the research team viewed the board and provided background information on sessions that were not obvious on the surface. This information was used to create the summaries of main PD design features that changed and are presented here. At this time, we are collecting input from the teacher leaders, and the full paper will include their insight and data from their sessions.

Findings

Due to limited space, we provide a brief summary of our findings here. The full paper will include our full findings with additional input from our teacher leaders.

RQ1. What were the core characteristics of PD design across the five years?

Initial design and structure of PD 1 and 2 (Fall 2020, Fall 2021)

The initial PD design in this study was guided by the experience of the lead project investigators who had conducted a successful research and development program with similar goals but working with secondary school teachers. Building off prior research and experience, the team prioritized active learning, hand-on activities involving CS tools, and free instructional materials for teachers to use (Desimone, 2009). They adapted materials from existing free online curricula to familiarize teachers of those resources (e.g., CS First by Google, https://csfirst.withgoogle.com/s/en/home; Code.org, https://code.org/; CS Unplugged. https://www.csunplugged.org/en/; Scratch, https://scratch.mit.edu/). However, due to COVID-19, the full design plan could not be implemented and the team adapted the face-to-face model to four virtual sessions of two hour length implemented during the Fall semester of academic year. While being mindful of the pandemic and the stress that teachers were experiencing at that time, the team worked with less than 10 teachers and prioritized supporting them more than implementing the project goals as envisioned. However, some teachers participated in the program and research conducted showed that their implementation focused mostly on literacy and closely paralleled what was presented in PD (Authors, 2023). Based on these insights, the team aimed to diversify content areas and extend the time on the sessions overall.

Structure of PD 3 (Summer 2022)

As the first face-to face PD in Summer 2022 that was now a four day full day Institute in the summer, the team incorporated more sessions on CS tools for education (e.g., Makey Makey, https://makeymakey.com/; Micro:bit, https://microbit.org/; OzoBots, https://ozobot.com/; ScratchJr https://www.scratchjr.org/; Sphero Central, https://edu.sphero.com/). The team included three sessions on Scratch that helped novice teachers create accounts, get introduced to the platform and use it. There were also new sessions educating teachers on relevant technology issues of cybersecurity, AI and ethics. Aside from a significant increase in time, the PD design made use of lunch sessions to promote networking with organizers having teachers meet by grades and content area focus on different lunch sessions across the days. Teacher leaders (i.e., teachers who had previously attended the PD and demonstrated leadership in implementing CS back in their schools) led three of the PD sessions and shared their experiences teaching their lessons. This year, three concurrent workshop tracks took place at the same location: one for middle and high school teachers, another for students, and a dedicated track for K-5 teachers. Teachers had the flexibility to attend sessions of interest across tracks, resulting in some cross-grade learning opportunities. Analysis of survey and interview data showed that elementary teachers, especially K-2 teachers identified the need for more materials catering to their student demographics and they emphasized the need for PD to incorporate training on accessible instruction techniques (Authors, 2022). A detailed analysis of teachers' lesson plans revealed two key insights: first, the need to shift focus towards adapting existing materials rather than creating new ones from scratch; and second, the importance of enhancing support for integrating CRP during the lesson planning phase to ensure teachers were effectively engaging students' identities and critical consciousness through their lessons (Authors, 2023). A teacher leader involved with one of the other tracks also became more involved in the teacher outreach and implementation support for elementary teachers after the summer PD.

Structure of PD 4 (Summer 2023)

During Summer 2023, CRP sessions were revised to include additional attention to foundational conceptualizations of culture to better prepare teachers to integrate strategies in culturally responsive ways. While maintaining the most valued sessions from the previous year, the team adapted the lesson planning template to more concretely address 3Cs (content, culture, and CS) and facilitated the lesson planning sessions to address this goal. A new session addressing accessibility was included as well as additional instructional materials for younger grades. Compared to the previous year, the organizers set aside more time for integrated lesson planning on the third and fourth day of the workshop to increase the support around creating lessons that integrated the 3Cs more thoughtfully. Finally, individual consultation time was included to provide personalized support. The evaluation report revealed that Scratch/ScratchJr, robots, and CS First were the most commonly used CS tools. Teachers most frequently planned to support academic success and cultural competence (Author 2023, Authors, 2024). The studies recommended diversifying the instruction of CT principles beyond algorithms and programming and supporting teachers to access more advanced principles of CRP (Author, 2023).

Nature of PD 5 (Summer 2024)

In the final institute in Summer 2024, the PD had the largest cohort of teachers attend. Building on the previous year's successes, the PD design retained a similar structure but introduced two significant modifications. First, CRP sessions were increased in length and differentiated to provide returning teachers with more advanced knowledge about CRP. Second, lesson planning workshops formed the main focus of the second half of the program, with concentrated efforts directed towards integrating the 3Cs. More time was provided on TK sessions. In particular, based on the teacher leader's suggestion to include sessions on Generative AI and the use of ChatGPT in lesson planning, three 45-minute sessions were included that introduced teachers to AI, and then towards teaching about GenAI and tools for using GenAI in their own teaching. As for CS content and tools, the evaluation report revealed that "algorithms & programming" and Scratch continued to dominate the focus of the PD, likely due to free resources surrounding these topics. All teachers submitted lesson plans demonstrating one solid application proposal. However, analysis of teacher interviews revealed more extensive plans for integrating their learning in the classroom. This suggests future PD should explore a wider range of tangible products or submissions that teachers can create to demonstrate their learning process more fully.

RQ2. How did PD design evolve over the years to become more contextually relevant for teachers?

Figure 2 illustrates the evolution of the PD, color-coded by the main dimensions of TPACK-CS/CT, CRP, and teachers' context. The graph highlights significant changes in PD duration during virtual and in-person sessions. In-person sessions saw an increase in time devoted to 3Cs integration in year 4 (as evidenced by the introduction of the purple bar representing 480 minutes), followed by a decrease to 345 minutes the following year to accommodate more CRP support. By year 5, which saw the highest teacher attendance, all dimensions of the TPACK-CS/CT framework achieved a relatively even distribution, ranging from 210 to 345 minutes (3.5 to 5.5 hours).

In addition, across all five years, teachers showed significant growth in CS knowledge and expressed high satisfaction with the workshop design. Many educators participated in school or district teams, collaboratively developing lessons and anticipating how this joint effort would enhance classroom implementation (Author, 2022, 2023, 2024).

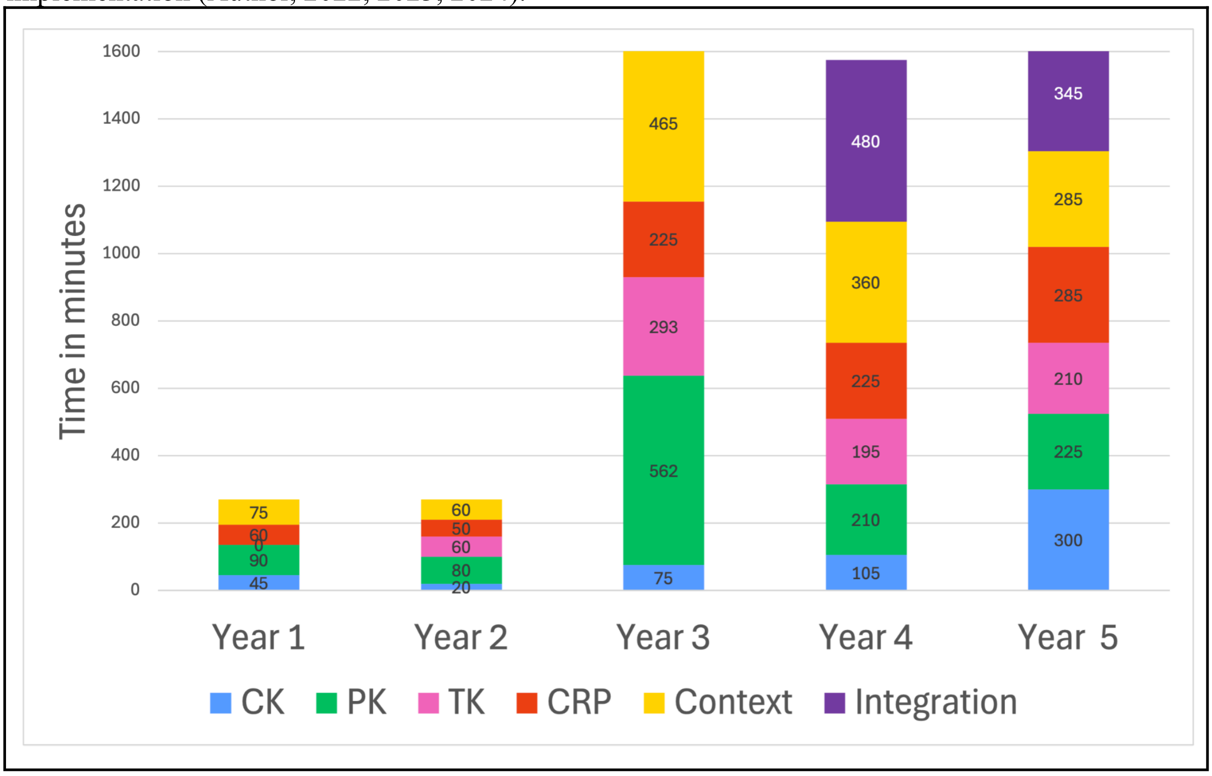

Figure 2. Evolution of TPACK-CT dimensions over the years

Discussion and Implications

Bringing CS into the elementary classrooms can have a significant impact on the number and diversity of students opting for a CS-related pathway during middle and high school years. The objective of this study was to explore how a PD on culturally responsive CS instruction for elementary teachers evolved over the course of five iterations to become more meaningful and useful to teachers in one mid-Atlantic state. The purpose of this analysis was to understand the design principles that led to successful PD design and understand the role of researcher-teacher partnerships in fostering a community of elementary CS educators. Analysis demonstrated how PD evolved across the dimensions of TPACK-CS/CT showing variation across how much time was spent on each dimension broadly. However, by the fifth year, an even distribution of the dimensions including content and CRP appeared to be more successful. Theoretically, this implies that the latest TPACK-CS/CT framework (Authors, accepted) is a useful guide for designing culturally responsive PD. Similar to Wang et al. (2014), the following factors led to improved PD design:

1. The involvement of teacher leaders, and the teacher leader who joined the team full time after summer 2022, made the sessions more accessible and relevant for teachers. They suggested topics that teachers would be interested in and that the researchers could provide additional training on, such as the AI sessions. Future PD should aim to nurture teacher-researcher relationships from the very beginning.
2. A meaningful integration framework: The framework of 3Cs (Content, CRP, and CS) that emerged over the years supported teachers to develop integrated lesson plans and it helped them submit a final plan by the end of the PD.
3. The emphasis on free and hands-on resources during PD facilitated teachers' adoption of CS tools in their instruction.

In conclusion, this study provides an evidence-based model of PD design within a Research-Practice Partnership (RPP) framework. By detailing key decisions and their rationale, we aim to offer valuable guidance for future educators, researchers, and policymakers engaged in teacher-as-researcher partnership projects, ultimately contributing to the advancement of culturally responsive CS instruction in elementary education.

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