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Data Fusion Insights on Indigenous-Serving Teachers' Implementation of Culturally Responsive Computing

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Indigenous communities remain among the most underrepresented groups in computing and STEM fields, facing systemic barriers to equitable participation in computer science (CS) education. This study examines how Indigenous-serving teachers, through a sustained professional development (PD) program, design and implement culturally responsive computing (CRC) curricula in Indigenous-serving schools. Guided by the research question: *How does sustained CS professional development inform the design of culturally responsive computing curricula by experienced CS teachers in Indigenous-serving schools?* We employed a natural language processing (NLP) data fusion approach that integrates text mining and qualitative thematic analysis to investigate how teachers incorporate Indigenous knowledge into computing instruction. Our findings reveal three emergent themes in teacher learning and lesson design: *Creating opportunities to access culture through computation, Leveraging Research and Critical Thinking Skills to Critically Engage Students with Computing, and Reflection, refinement, and professional growth through ongoing collaboration*. These themes underscore the impact of CRC on bridging cultural traditions with computing, fostering engagement, and enhancing Indigenous students' sense of belonging in CS. By supporting teachers in developing culturally relevant lessons that integrate storytelling, traditional arts, and computational thinking, this research contributes to the broader discourse on inclusive CS education. This study informs future efforts to expand Indigenous student participation in computing by highlighting the role of culturally sustaining pedagogy in professional development and curriculum design.

INTRODUCTION

Broadening participation in computer science (CS) has become a national priority, with the federal government endorsing numerous funding initiatives to promote CS education for all students (Goode et al., 2020). Ensuring that K–12 students engage in high-quality CS education before entering college and choosing career pathways is essential (Rich et al., 2024). However, historically underrepresented students and their teachers continue to face persistent barriers in CS education (Quigley et al., 2023; Rich et al., 2024; Yan et al., 2024). Among these groups, Indigenous students remain the most underrepresented in computing and STEM fields, facing significant challenges such as difficulties in recruiting and retaining qualified teachers, along with unequal access to resources and infrastructure (Slater et al., 2024). These systemic barriers, compounded by historical and cultural disconnections, underscore the urgent need for curricula that are intentionally designed to meet the unique needs of Indigenous communities. Addressing these challenges requires a deep understanding of the factors limiting Indigenous participation in CS education, which can inform research and practice on effective pedagogical approaches in Indigenous-serving schools. In response, various research initiatives, foundations, and universities have undertaken efforts to mitigate these barriers and develop inclusive educational frameworks.

Research shows that Indigenous students thrive when curricula are culturally relevant and grounded in their lived experiences (Barnhardt, 2015;

López-Quiñones et al., 2023; Searle & Kafai, 2015). Programs such as the Smithsonian's National Museum's *Indigenous Knowledge 360* have proved significant improvements in learning outcomes for Indigenous students by integrating cultural knowledge into educational materials (Smithsonian, 2017). Culturally Responsive Computing (CRC) frameworks have been developed to incorporate Indigenous perspectives into CS education. For example, research groups have designed computing curriculums to include designing apps to document food security, e-textiles, and storytelling (Clark et al., 2023; Kapor Center, 2024; Searle et al., 2023). Similarly, Wind River Elementary Schools in Wyoming developed a culturally responsive CS curriculum using Scratch-based lessons to increase student engagement, confidence, and successful application of CS concepts (Wilson et al., 2023). Despite these promising approaches, research on CRC in the Four Corners region—one of the largest Indigenous regions in the U.S.—remains limited beyond preliminary studies (Searle & Kafai, 2015). This gap presents an opportunity to explore how CRC can be effectively integrated into Indigenous-serving schools from this region. The paper addresses this need by bringing together experienced CS educators to develop culturally responsive curricula for Indigenous-serving schools. Through a sustained professional development (PD) program, educators developed the knowledge and skills necessary to infuse computing into Indigenous culture. This paper answers the following overarching question: *How does sustained CS professional development inform the design of culturally responsive computing curricula by experienced CS teachers in Indigenous-serving schools?* By answering this research question, this research aims to contribute to the development of inclusive CS education that fosters Indigenous students' engagement, sense of belonging, and academic success in computing.

BACKGROUND

Teaching CS concepts presents significant challenges, requiring substantial effort from educators to effectively convey content and guide students in applying computational thinking skills (Lewis et al., 2019). Teachers are crucial in facilitating CS learning, yet many lack the necessary preparation and support. To address these challenges, specially designed professional development (PD) programs have emerged in the past few decades to equip teachers with the skills and knowledge needed to integrate CS into their instruction. These PD programs employ diverse approaches, including in-person workshops, summer institutes (Menekse, 2015), online learning platforms (Qian et al., 2018), professional learning communities (PLCs)

(Darling-Hammond et al., 2017), and teacher-led training cycles. The overarching goals of these initiatives are to enhance teacher capacity, improve self-efficacy, expand K–12 CS participation, and establish scalable and sustainable models for CS PD (Ni et al., 2023).

Benefits of CS PD

Participation in CS PD has been shown to yield multiple benefits for teachers. One of the most significant advantages is an increase in teacher self-efficacy, which is closely linked to both their professional learning experiences and their effectiveness in implementing CS instruction in the classroom (McGill et al., 2021). Teachers with higher self-efficacy are more likely to experiment with new teaching strategies, integrate computational thinking into various subjects, and engage in continuous professional growth (Yadav et al., 2021). Studies have demonstrated that teachers who participate in CS PD exhibit increased confidence in teaching computing concepts. For example, Bausch (2023) found that middle school educators who completed a CS PD program reported greater self-efficacy in app creation and in teaching CS and digital literacy. Moreover, teacher self-efficacy has been directly linked to student outcomes. Teachers with strong confidence in their CS knowledge positively influence students' engagement, learning outcomes, and information literacy skills (Wu et al., 2022). Research further indicates that teacher content knowledge, collaborative engagement, and instructional strategies significantly impact students' academic performance in computational thinking (CT) concepts (Kong & Lai, 2023). Additionally, elements such as classroom support, goal setting, workload management, and teaching experience contribute to student achievement in CS education (McGill et al., 2020; Sun et al., 2023). Another key benefit of CS PD is the development of PLCs that help mitigate teacher isolation. Many CS teachers report feeling isolated, as they are often the only CS instructor at their school (Goode et al., 2020; Yadav et al., 2017). By fostering a sense of community among educators, PLCs promote resource sharing and the collective learning process (Schwarzhaupt et al., 2021), enhance instructional quality and promote sustained engagement with CS teaching methodologies (Woodland, 2016). Overall, CS PD equips teachers with the skills needed to integrate innovative technologies and pedagogical strategies into their teaching (Du et al., 2023). PD programs help teachers stay up to date in computer science, so they can create effective and engaging lessons for their students, thereby bridging the gap between theory and practice in CS education (Du et al., 2023).

Challenges in CS PD

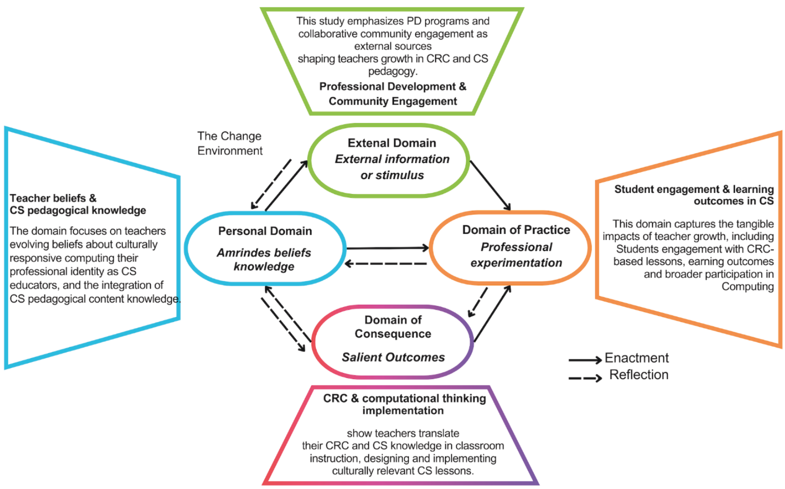
Despite these clear benefits of CS PD, implementing effective training programs in rural and Indigenous communities remains a challenge (Hill & Fancsali, 2021; McGill et al., 2022). Many rural schools struggle to attract and retain qualified CS educators, leading to significant disparities in access to CS education. For instance, the Hawaii Department of Education reported that only 0.5% of new teachers specialize in CS, highlighting a critical shortage of trained educators in the region (Slater et al., 2024). Similarly, in Idaho's Indigenous communities, a lack of STEM-trained educators places additional strain on existing teachers, making it difficult to sustain high-quality CS instruction (Oh et al., 2024). These challenges underscore the need for targeted interventions that address the unique barriers faced by Indigenous-serving schools. Ensuring equitable access to CS education requires culturally responsive PD programs that enhance teachers' technical skills and integrate Indigenous knowledge and perspectives into computing curricula. By leveraging culturally sustaining pedagogies and collaborative learning models, CS PD can empower teachers to create meaningful and inclusive educational experiences that resonate with Indigenous students. The theoretical framework described below builds on this background.

THEORETICAL FRAMEWORK

Engaging and meaningful learning experiences are fundamental to teachers' professional development, as they foster the construction of new knowledge and instructional practices. Research highlights that engagement, coupled with expert guidance, plays a critical role in reshaping teachers' existing knowledge through interactive and reflective learning models (Reiman et al., 1997). This perspective aligns with the understanding that professional growth is a transformative journey, enriched by external support and ongoing practice. Central to this paper is the Interconnected Model of Professional Growth (IMPG) (Clarke & Hollingsworth, 2002), which identifies four interrelated domains that actively shape teachers' professional development through reflection and practical application. The Interconnected Teacher Model of Professional Growth (ITMPG) (Justi & Van Driel, 2006) underscores the complexity of teacher learning by illustrating multiple pathways through which professional growth unfolds. It also redefines enactment as more than just the implementation of isolated teaching actions; rather, it refers to the intentional application of pedagogical beliefs and strategies in real-world classroom settings. This perspective positions teacher learning as a dynamic process, where various forms of knowledge — including content knowledge, pedagogical knowledge, and pedagogical content knowledge (Archambault & Barnett, 2010; Mishra & Koehler, 2006) — are actively constructed through participation in professional development programs and classroom experiences. Given the ITMPG framework's emphasis on active knowledge construction, this paper adopts it as a foundational model for analyzing how teachers enact CS pedagogy after participating in a sustained PD program. Specifically, this research investigates how CS educators integrate CRC and CT into their teaching practices. It explores how teachers' engagement with IMPG facilitates shifts in their pedagogical beliefs, instructional strategies, and professional identities, ultimately shaping their ability to create inclusive and meaningful CS learning experiences for Indigenous-serving students.

Figure 1

Theoretical Framework



Note. The ITMPG as the framework for this paper, encapsulates Indigenous-serving teachers' navigating the CRC-focused PD program, highlighting the dynamic interplay between professional learning, instructional practice, and student outcomes.

ITMPG as a Framework

ITMPG provides a comprehensive framework for understanding how CS teachers develop and implement CRC and computational thinking after participating in professional development. By emphasizing the External Domain of Professional Development & Community Engagement, the model captures how sustained PD programs and community collaborations influence teachers' beliefs and instructional practices. The Personal Domain of Teacher Beliefs & CS Pedagogical Knowledge highlights the evolving perceptions of CS educators as they integrate CRC into their teaching. The Domain of Practice, focusing on CRC & CT implementation, reflects how teachers translate their learning into culturally relevant CS instruction. Finally, the Domain of Consequence, centered on student engagement & learning outcomes in CS, underscores the tangible impact of teachers' growth, shaping students' participation, and success in computing.

Recent studies have utilized the ITMPG to inform and guide CS PD initiatives (Ni et al., 2023). For instance, the Science Teaching Inquiry Group in Computational Thinking program applied the model to examine the professional growth of elementary school teachers in computational thinking PD (Ketelhut et al., 2020). Clarke and Hollingsworth (2002) emphasized that teachers are active learners who evolve their teaching practices by engaging in reflective PD experiences and real-world enactment. In this paper, the ITMPG framework is applied as follows. The Personal Domain encompasses CS teachers' evolving knowledge, attitudes, and beliefs about computing education. The External Domain reflects the influence of long-term PD and institutional support in facilitating knowledge integration. The Practice Domain includes the new teaching methodologies that educators develop and implement in their classrooms. The Consequence Domain captures the outcomes of culturally responsive CS instruction, particularly in Indigenous-serving schools. By employing ITMPG, this paper provides a structured understanding of how CS educators navigate professional growth, implement culturally responsive computing, and enhance equitable access to CS education for Indigenous students.

This paper addresses a significant gap in research CRC in Indigenous-serving schools, specifically within the Four Corens region. While previous studies have explored CRC in other Indigenous contexts, little extensive research has examined how experienced CS teachers design and implement computing curricula for Indigenous students after participating in a sustained PD program. This paper supports teacher development by providing insights into how PD enhances teacher efficacy, self-confidence, and lesson implementation. It contributes to equity in computing education by addressing structural barriers Indigenous students face and highlights Indigenous perspectives in CS education, which is critical for creating inclusive and sustainable computing pathways. Hence, this paper will discuss the best practices for designing CRC curricula in Indigenous-serving schools.

REVIEW OF LITERATURE

CS PD's Role in Supporting Marginalized Learners

Efforts to expand computer science (CS) education increasingly emphasize reducing disparities in access for underrepresented groups. Numerous nonprofit organizations, universities, and research initiatives promote CS professional development (PD) programs that equip educators with the skills necessary to implement culturally responsive computing (CRC). These programs recognize that CS teachers are pivotal in creating equitable learning environments, especially for Indigenous, rural, and other historically marginalized students. For example, the Exploring Computer Science (ECS) curriculum integrates CRC through activities such as e-textiles, CodeQuilt, and quilting restoration, engaging Indigenous students in designing artifacts reflective of their culture (Fields & Kafai, 2023; Goode et al., 2014). Further efforts include the partnership between Kent State University and Akron Public Schools, which employs a co-design approach that unites APS teachers and university researchers in developing CS modules and lesson plans (Novak & Khan, 2022). By leveraging expertise from computer science professionals, instructional designers, and diversity specialists, the program supports the implementation of inclusive, culturally relevant CS curricula. Additionally, the Let's Talk Code initiative offers PD opportunities for middle and high school educators in the southwestern United States, with an emphasis on place-based and culturally relevant computing education (Amresh et al., 2024; Prescott et al, 2024; Yan et al., 2024).

The structure and delivery of these CRC PD programs vary widely, from single-session workshops to extended, multi-day training. For instance, the BootUp PD initiative on the Wind River Reservation offers four-hour training sessions delivered in person or virtually (Rich et al., 2024). Similarly, a research-practice partnership in Hawaii provides CS PD via online modules, in-person workshops, and embedded PD, where experienced educators mentor novice teachers during a summer learning program (Slater et al., 2024). In contrast, the ECS PD model employs a week-long intensive training using a teacher-learner-observer framework that allows participants to engage in instructional practice, curriculum revision, and collaborative discussions on culturally responsive computing (Fields & Kafai, 2023; Goode et al., 2014). Together, these diverse models underscore the growing need for contextually relevant, equity-centered PD to support CS educators in marginalized communities.

The Role of Culturally Responsive Pedagogy in CS PD

Recent studies highlight the significant role of culturally responsive pedagogy (CRP) (Ladson-Billings, 2000) in enhancing teacher self-efficacy within CS education (Grover & Pea, 2013; Malakul & Sangkawetai, 2024). PD programs that integrate CRP effectively equip educators with both content knowledge and instructional strategies necessary for implementing culturally responsive teaching practices (Codding et al., 2021). Teachers engaging in CRP-based PD develop a deeper understanding of these practices, thereby increasing their confidence and capacity to teach diverse student populations (Codding et al., 2021). Embedding CRP in CS PD also correlates with higher student engagement; when curricula reflect students' cultural identities and lived experiences, learners are more likely to feel valued, motivated, and involved (Malakul & Sangkawetai, 2024). For example, students participating in the ECS curriculum have shown increased confidence in succeeding in CS, improved learning outcomes, and enhanced self-assurance in developing 21st-century skills (Qazi et al., 2020). Furthermore, culturally responsive computing, an extension of CRP in CS education, has been recognized as an effective approach for addressing educational inequities, mitigating psychosocial barriers, and leveraging students' cultural knowledge as a resource for computational learning (Grover, 2024; Madkins et al., 2019). The ECS PD model, in particular, encourages educators to critically examine their beliefs about student potential by challenging deficit-oriented perspectives and fostering reflective practices on the intersections of educational opportunity and systemic inequities. These findings underscore the essential role of PD programs that integrate both CRP and CRC in preparing educators to provide equitable CS learning experiences.

CRC as An Approach to CS Education

Expanding CS education for historically underrepresented K–12 students necessitates approaches that move beyond the traditional content-agnostic, concept-centric focus on computational problem-solving (Madkins et al., 2019; Pollock et al., 2017). While traditional methods have yielded success in predominantly White, well-resourced schools, they often neglect the cultural, social, and contextual dimensions that shape students' learning experiences, leaving Indigenous, Alaskan Native, and Pacific Islander students, among others, underrepresented in CS and the broader STEM pipeline (Abrams et al., 2013).

In contrast, CRC, grounded in the principles of CRP (Ladson-Billings, 2000), has garnered significant attention as a strategy for fostering inclusive and equitable computing education (Xie & Ferguson, 2024). By integrating students' cultural knowledge, identities, and community contexts into computing instruction, CRC creates meaningful learning experiences that enhance engagement and retention in CS (Moudgalya et al., 2024). CRC approaches have been applied to support technological learning, improve academic achievement, and sustain long-term STEM participation among marginalized students (Gay, 2010; Scott et al., 2015). For instance, the COMPUGIRLS after-school program, which engaged African American and Latino girls in community-centered projects, resulted in sustained participation and boosted confidence in CS (Scott & White, 2013). Similarly, mentorship-based game design programs have expanded computing opportunities for underserved students by emphasizing collaboration and culturally relevant pedagogy (Clark & Sheridan, 2010). Recent initiatives have further advanced computing education in Indigenous communities by integrating traditional knowledge and local cultural practices. The use of e-textiles and coding to connect computing with Indigenous craft traditions has notably increased student interest and engagement in STEM (Fields & Kafai, 2023; Kafai et al., 2014; Searle & Kafai, 2015). For example, educators in the Wind River Elementary Computer Science Collaborative participated in BootUp PD workshops focused on culturally sustaining CS education, co-designing lessons with community members that incorporated traditional language and storytelling into Scratch programming (Rich et al., 2024). Similarly, Hawaiian education initiatives have revised CS curricula to better reflect Indigenous perspectives, embedding Hawaiian-centered pedagogy and cultural values into computational learning experiences (Slater et al., 2024). These interventions demonstrate the potential of culturally responsive CS education to bridge the gap between technology and Indigenous knowledge, offering a more inclusive and contextually relevant approach to computing education for Indigenous-serving communities.

METHODOLOGY

Setting

The data analyzed for this study is a part of a multi-year study set in a collaboration between university researchers, K–12 schools serving Indigenous communities, and teachers teaching in this schools. This paper presents an analysis of a subset of the study's data, specifically, how teachers and researchers worked together to create and improve computer science lessons that connect to Indigenous culture. The team used an iterative, evidence-based process and met computer science standards from the K–12 CS Framework (CSTA, 2017) and focused on teaching students how to program and build apps. Four learning objectives were included in the course: 1) What computers are and how they work; 2) What is data and how computers manipulate and use data; 3) What is a computational problem and how to solve it; and 4) How computer applications impact the world. Teachers engaged in online professional development (PD) and had weekly online meetings to talk with each other and get help from the research team. The learning materials were available on the popular learning platform, Canvas, with 12 modules in total. The weekly meetings were held virtually from Fall 2023 to Fall 2024. Teachers were asked to design CRC lessons that connected computer science to Indigenous culture, choosing from topics like basket weaving, rug design, sculpting, astronomy, weather, farming, music, and community activities.

Participants

Seven teachers serving schools around the Four Corners region of the United States were recruited to participate in the program. The recruitment criteria for teaching fellows included schools with less than 90% Indigenous students and teachers offering a computing course (Computer Science, Information Technology, Robotics, Cybersecurity) course. The schools were selected because of their high percentage Native American students and high need populations (economic & academic). The student population at these schools have high rates of poverty and low rates of achievement in Math and Science, lower than the state average. A list of the teaching fellows' demographics is provided in Table 1. We refer to the participants as teachers, teaching fellows, and Teacher A-G, which are pseudonyms. Demographic and achievement data from participating schools revealed lower than state-average mathematics and science scores, alongside a high prevalence of students qualifying for free and reduced-price lunch and a significant representation of Indigenous students.

Table 1

Demographic Details of Each Participating Teacher's School

Teacher	A	B	C	D	E	F	G
Race	Indigenous/ Female	Indigenous/ Female	Indigenous/ Male	White/ Female	Black/ Male	Indigenous/ Female	Asian/ Male
School Types	Bureau of Indian Education (BIE)	BIE	Regular public school	BIE	BIE	College academy	Regular public school
% Indigenous	95.9	95.9	97.4%	100%	100%	85%	79%
Median Income	18K	18K	29K	67K	38K	NA	61K
Teaching Grade	10–12	After-school	6–8	7–8	11–12	10–12	After-school

Data Collection

Discussion Board

Teaching fellows posted their thoughts using about 200 words for each module and replied to at least two peers on Canvas' discussion board. Each module includes one or two discussion tasks.

Personal Reflection

Seven teachers wrote about 300–500 words of personal reflections after finishing each module's learning activities. Researchers copied and pasted each discussion into an Excel file. Researchers copied and pasted each teaching fellow's reflection into the CSV file.

Lesson Plan

Each teacher developed two CRC lesson plans following a four-step iterative process that included co-development of the lesson with the researchers and other teacher fellows, classroom observations, revisions, and implementation. Each lesson plan was meant to be implemented over a duration of 3 class periods. The researchers visited and provided feedback on the lesson plan, following which the teachers revised and finalized the lesson plan. Seven participating teachers submitted 20 lesson plans in total. Table 2 summarizes the lesson plans created and implemented by the teacher fellow.

Table 2

A summary of the Lessons Developed by Each Teacher

Teacher	Lesson Plan and Materials Used	Key Goals	Brief Description
Teacher A	Sphero a-maze-ing traditional trails Sphero Bolt robots, Sphero Edu App, tablets, design materials (paper, markers, stencils).	Merge Hopi traditional designs and coding; program a Sphero robot to navigate a culturally inspired maze.	Students research Hopi symbols, design a maze incorporating these cultural elements, and use block coding to program a Sphero robot to traverse the maze.
Teacher B	Exploring Micro:bit using micro chat with Indigenous languages Micro:bit, laptops with internet access	Explore coding concepts with Micro:bit; integrate Indigenous (Hopi) language; promote cultural preservation through technology.	Students work in pairs to write pseudocode, program Micro:bit with Hopi phrases, and reflect on how technology can preserve Indigenous language.
Teacher C	Navajo rug geometric patterns Block coding platforms (e.g., Code.org), Dash robots, Sketch Kit	Use code to create geometric patterns inspired by Navajo rugs; link cultural heritage with computational art.	Students use block-based coding and robotics to design and program geometric patterns that reflect traditional Navajo rug designs.
Teacher D	E-Textiles (bookmark and bracelet) Conductive thread, flexible circuit boards, batteries, LEDs, LilyPad microcontroller, sewing tools, fabric.	Introduce culturally inspired e-textiles; integrate students' cultural identities into design; develop soft electronics skills.	Students design and construct e-textile projects (a bookmark and a bracelet) that incorporate traditional design elements and electronic components.

Teacher	Lesson Plan and Materials Used	Key Goals	Brief Description
Teacher E	Bias in AI Google Teachable Machine, Scratch, Google AI experiments, computers/tablets, presentation tools.	Explore bias in AI systems; analyze its societal impact; discuss strategies for mitigation.	A lesson featuring lectures, case studies, group discussions, and role playing that investigates the types and impact of bias in AI, with attention to ethical and cultural issues.
Teacher F	Computational thinking and quilting Code Crafters Quilt Generator, computers, fabric, sewing machine, and optional Micro:bit or Arduino for interactive elements.	Bridge traditional quilting with computational design; develop geometric and algorithmic thinking through quilt design.	Students design quilt blocks using geometric patterns, digitize their designs with the Code Crafters Quilt Generator, and explore the cultural significance of quilting over several sessions.
Teacher G	Microbit robotics dance Micro:bit, Yahboom tiny:bit robot cars, Makecode (Micro:bit programming platform)	Teach Micro:bit programming and robotics; replicate traditional Navajo Round Dance movements with robots.	Students learn block-based programming, sensor integration, and robot choreography to have micro:bit –driven robots perform a dance inspired by the Navajo Round Dance.

Data Analysis

A data fusion approach was used to analyze the lesson plans, personal reflection, and discussion board contributions from all teachers. Data fusion is an analytical approach that involves combining data from multiple sources to create a more comprehensive and accurate understanding of a phenomenon (Chango et al., 2022). Specifically, topic modeling was conducted on teaching fellows' discussion and personal reflection, while lesson plans and discussion board contributions were analyzed qualitative analysis. We first analyzed the fellows' discussion and personal reflection, then used topics emerging from the topic modeling as a priori codes to code teachers' lesson plans. This strategy helped us maintained objectivity in identifying broad patterns in discussions and personal reflections and then elaborate the topics' relevance to the lesson plans and discussion board contributions through qualitative thematic analysis (Clarke & Braun, 2017). This process is detailed below.

Methodological Approach 1: Topic modeling

Topic modeling is a process used in natural language processing to discover hidden topics within a collection of documents automatically. One of the most common algorithms for topic modeling is Latent Dirichlet Allocation (LDA). We used a Python module to apply the algorithm and analyze data. Topic modeling follows the following process:

Preprocess

Preprocessing involves cleaning and transforming transcripts. We cleaned and transformed teachers' discussions and personal reflections in each module. The first step in this procedure is to split a text into individual words or tokens called **tokenization**. For example, the sentence: *"Teachers discussed strategies for integrating computational thinking."* becomes: *["Teachers," "discussed," "strategies," "for," "integrating," "computational," "thinking"].* Tokenization is crucial for text analysis because it converts unstructured text into a structured format for further processing.

The second step is to do **Stopword Removal.** Some words, like "the," "is," and "and," frequently appear in the text but do not contribute significantly to meaning. Removing them helps focus on the more important content. For example: "*Teachers discussed strategies for integrating computational thinking.*" After stopword removal, becomes ["*Teachers,*" "*discussed,*" "*strategies,*" "*integrating,*" "*computational,*" "*thinking*"]. This makes text analysis more efficient by reducing unnecessary words.

Step three of the preprocess is **stemming/lemmatization**, which reduces words to their root form. For example, stemming cuts off word endings based on simple rules. Example: "discussed" → "discuss," "running" → "run." However, it may produce non-standard words ("computational" → "comput"). Lemmatization uses a dictionary to find the correct base form of words. Example: "discussed" → "discuss," "better" → "good", which is more accurate than stemming.

The final preprocessing step is **Transform Case**, which converts all text to lowercase to ensure consistency in text analysis. For instance, "Teachers discussed Computational Thinking." After applying this transformation, it will become "teachers discussed computational thinking." This helps prevent duplicate entries due to case differences (e.g., "Computational" vs "computational").

Vectorization

Vectorization converts text into numerical data. This process transforms textual data into a numerical format suitable for machine learning algorithms. Most algorithms cannot analyze text data directly, so vectorization changes words or phrases into numerical representations. We converted the cleaned and transformed transcripts into a numerical format that a topic modeling algorithm can comprehend using the bag of words (BoW) method, representing the frequency of words in each document. For example, if we have two sentences: (1) "Teachers discuss computational thinking," and (2) "Students learn computational thinking." The unique words (vocabulary) in both documents are: ["Teachers," "discuss," "computational," "thinking," "Students," "learn"]. Each sentence is then represented numerically as a vector of word frequencies: [1, 1, 1, 1, 0, 0] and [0, 0, 1, 1, 1, 1]. The numbers indicate how often each word appears in the documents.

Applying Latent Dirichlet Allocation

Once the text is vectorized using BoW, a topic modeling algorithm (Latent Dirichlet Allocation, LDA) can analyze word usage patterns and group similar words together to identify topics. This popular topic modeling algorithm identifies hidden topics in text documents. It assumes that each document is a mixture of different topics, and that each topic is a mixture of words. This enables researchers to recognize recurring topics or themes in discussions and reflections. Each document (discussion transcript) will have a probability distribution over these topics. For example, if LDA is applied to teachers' discussion transcripts, it might uncover topics such as:

- Topic 1: *{computational, thinking, integration, students, learning}*
- Topic 2: *{assessment, feedback, reflection, experience, improvement}*
- Topic 3: *{collaboration, group, discussion, participation, engagement}*

Testing a Range of Topics

We tested a range of topics (3–10) to extract and find the highest coherence value. Since LDA requires specifying the number of topics before running the model, we tested different topic numbers (K) to determine the best fit. If K is too low, broad topics may merge together, losing specificity. If K is too high, topics may become fragmented and less meaningful. Testing K = 3–10 helps find a balance between interpretability and coherence. A higher coherence value means that the words in a topic are more related and meaningful. For example, a topic with the words *{computational, thinking, programming, coding, logic}* is more coherent than one with *{computational, teacher, apple, learning, walk}*. The optimal number of topics is typically the one that maximizes coherence. In this analysis, the optimal number was five. Through coherence value analysis, we ensure that the topics extracted from transcripts are both meaningful and interpretable.

Methodological approach 2: Qualitative analysis.

To systematically analyze how teaching fellows integrated CRC into their lesson plans, we employed qualitative analysis. The following methodological steps were taken to ensure rigor, reliability, and interpretive depth in analyzing the lesson plans.

Using a priori codes from topic modeling for deductive coding.

Through the process described above, broad themes identified through LDA were used a-priori codes. This was required to understand how and the extent to which key CRC and CT components of the lessons were translated into teachers' curriculum designs and appeared in their reflections. Each teacher's lesson plan, personal reflection, and discussion board contributions were collected and analyzed to identify and analyze patterns. Code saturation was achieved through iterative axial coding and constant comparison, where researchers continuously refine their coding scheme until no new codes or themes emerged, and existing codes were thoroughly represented across the data. Throughout this process the researchers maintained detailed coding logs and reflexive journaling to demonstrate when all relevant aspects of the data were captured. Intercoder agreement and peer review further enhance the reliability of saturation, signaling that the analysis has reached a point where additional coding yields no significant new insights.

We found three final themes and organized the findings based on these. This integrated data fusion approach allowed for a comprehensive examination of CS teachers' reflections, discussions, and curriculum development, contributing to a deeper understanding of how CRC is enacted in Indigenous-serving schools.

FINDINGS

Three themes emerged from the analysis: opportunities to access culture through computation, leveraging research and critical thinking skills to critically engage students with computing, and reflection, refinement, and professional growth through ongoing collaboration. The findings are organized by theme, and participant data are used to describe and elucidate each theme. Table 3 summarizes the three themes and how the teaching fellows' lesson plans demonstrate them.

Table 3

An Overview of the Paper's Data Fusion Analytical Approach

Topic identified	Top 5 Keywords, N	Description	Lesson topics	Most prominent qualitative theme
Culture	access, Navajo, Hopi, district, language, opportunities N=6	Teachers incorporated Indigenous languages, traditions, and cultural contexts into CS lessons to enhance cultural relevance and student engagement.	Scratch storytelling, Spero dance, Micro:bit name display and dance, Scratch storytelling, Rug weaving	Opportunity to access culture through computation Leveraging research and critical thinking skills to critically engage students with computing
Designing artifacts using computation	sound, designer, plan, change, perspective N=7	Teachers guided students in designing and prototyping computing-based projects that computation and problem solving with students' culture.	Laser Guitars, traditional rug design	Opportunity to access culture through computation Reflection, refinement, and professional growth through ongoing collaboration
AI Knowledge and Concepts	AI, knowledge, concepts, help, implementation N=2	Teachers introduced AI concepts, ethical considerations, and applications relevant to Indigenous communities, including issues of AI bias and data sovereignty.	Using AI to train facial recognition, Quick draw.	Leveraging research and critical thinking skills to critically engage students with computing Reflection, refinement, and professional growth through ongoing collaboration

Topic identified	Top 5 Keywords, N	Description	Lesson topics	Most prominent qualitative theme
Integrating a range of computational technologies	component, classroom, technology, examples, app N=7	Teachers integrated various computing technologies to support interactive, culturally meaningful learning experiences.	Hopi Dancing with Sphero; Scratch storytelling, Arduino Laser guitar, Micro:bit display, rug design.	Opportunity to access culture through computation Leveraging research and critical thinking skills to critically engage students with computing Reflection, refinement, and professional growth through ongoing collaboration
Computational thinking	thinking, example, computational, way, today N=7	Teachers embedded computational thinking skills such as decomposition, pattern recognition, and abstraction into culturally relevant lesson designs.	Micro:bit, rug design, AI facial recognition.	Opportunity to access culture through computation Leveraging research and critical thinking skills to critically engage students with computing
Research skills	skills, process, curriculum, research, future N=7	Teachers applied research methodologies learned in PD to design culturally responsive computing lessons informed by Indigenous knowledge and perspectives.	Design of rugs and the Laser guitar, storytelling, language use and display, robotic dance.	Opportunity to access culture through computation Leveraging research and critical thinking skills to critically engage students with computing

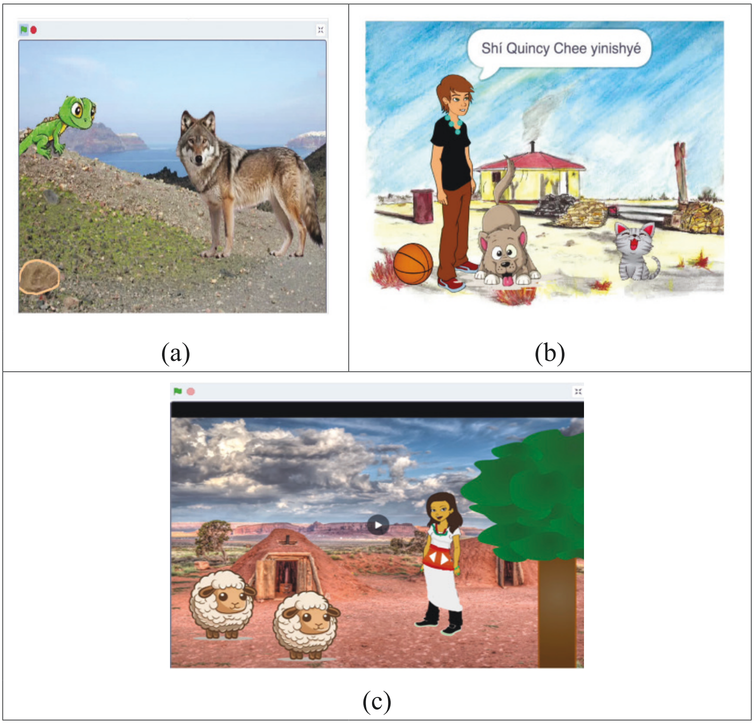
Note. The first column indicates prominent topics identified through LDA and the final column indicates the themes identified through thematic analysis.

Creating opportunities to access culture through computation

A key finding highlights how teachers provided students with opportunities to engage with their traditions through CS lessons. This integration of computing into Indigenous culture, i.e., language, storytelling, arts, music, and food was a central component of lesson plans through which teachers fostered culturally relevant and meaningful learning experiences that strengthened students' connections to both their culture and computational thinking. For example, Teacher C designed a Scratch (Lifelong Kindergarten Group, 2007) storytelling project (Figure 2 a–c) incorporating Navajo language and geographic elements (e.g., Hogan structures and Navajo reservation landmarks). To scaffold student learning, the lesson began with CSFirst instructional videos, which guided students through the story creation process in Scratch. After completing these foundational activities, students applied CS concepts such as sequencing, debugging, and decomposition to develop their own digital stories. To ensure authentic representation of the Navajo language, Teacher C required students to integrate sequential dialogues in both English and Navajo (Diné) text or audio recordings. Diné language resources and the Scratch recording tool were introduced to students at the same time. Additionally, students were encouraged to incorporate personal and community-based elements, such as family members, local traditions, and significant places in their narratives.

Figure 2

The Scratch Storytelling Project Depicting the Story's Frames and the Contextual Use of Language



Note. Figure 2 (a, b, c) highlights students integrating Navajo folklore and language into Scratch dialogues, merging storytelling with computational thinking.

Beyond classroom instruction, these projects extended to community engagement. Once students completed their Scratch stories, they were invited to present their projects at a school-wide cultural night, where parents and community members observed how traditional storytelling was brought to life through computational tools. These culturally responsive CS lessons also demonstrated how computing education can serve as a bridge between Indigenous culture and modern technology. By integrating language, storytelling, and community-based learning, teachers enhanced student engagement, deepened their connection to heritage, and fostered a more inclusive approach to computing education, aligning with the broader goal of expanding equitable access to CS for Indigenous learners. Students developed an appreciation of the role of Indigenous storytelling traditions in their culture, demonstrating the transformative impact of culturally responsive CS education.

Figure 3

Indigenous Arts Such as the Hopi Dance Inspired Teachers and Students to Code a Micro:bit to Replicate Dance Movement

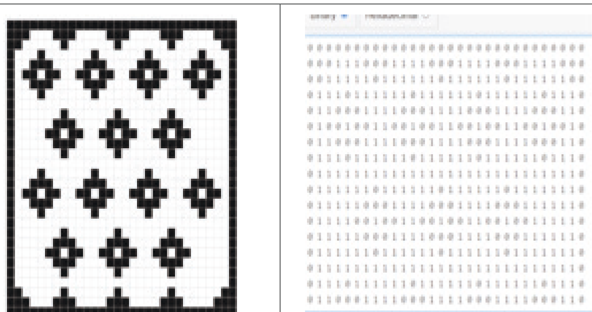
(a) (b)

Note. Figure 3a shows the micro:bit robot the students coded and Figure 3b shows the dance movements the students researched.

Teachers also integrated Indigenous art and computational tools into learning experiences. Figure 3 illustrates an example of such integration into CRC lesson plans, showcasing web-based coding, physical computing, and hybrid approaches. For example, Teacher G initiated lessons using Micro:bit (Micro:bit Educational Foundation, 2016) to display the names of learners, their friends, and pets. Teacher G also developed the Robotics Dance project to support students in drawing inspiration from the dance's rhythm and the associated traditional regalia. Students first studied traditional Navajo Round Dance movements and regalia before programming their Micro:bits to replicate these dance sequences (Figure 3a–b). Teacher F also incorporated traditional Indigenous art forms (Figure 4a–d) into computing lessons, helping students explore the intersection of cultural artistic expression and digital technology. In one engagement, students created rug designs on worksheets that represented traditional rug patterns in the binary system (Figure 4a), encoding them into binary digits to translate traditional patterns into a computational format through Code.org (Code.org, 2013) (Figure 4b). Students then converted these designs into a pixelation widget, demonstrating how computational representations can digitize and reinterpret traditional artistic forms. This lesson also encouraged critical discussions on the benefits and challenges of digitizing Indigenous art, prompting students to reflect on how technology can preserve, transform, or potentially commodify cultural artifacts as they translated the design to a weave (Figure 4c) on a small loom (Figure 4d). Building on this foundation, Teacher F merged the cultural and artistic design process of quilting with a computational design process, integrating algorithmic thinking and computational modelling. Students followed an iterative design cycle, creating quilt blocks that represented traditional quilting patterns and were digitized using computational tools. As a culminating experience, students posted their quilt-making algorithms on a school website, encouraging others to recreate, modify, and build upon their designs, reinforcing the collaborative and open-ended nature of computational creativity.

Figure 4

Pixelation Widget and Arts



(a) (b)

(c)

(d)

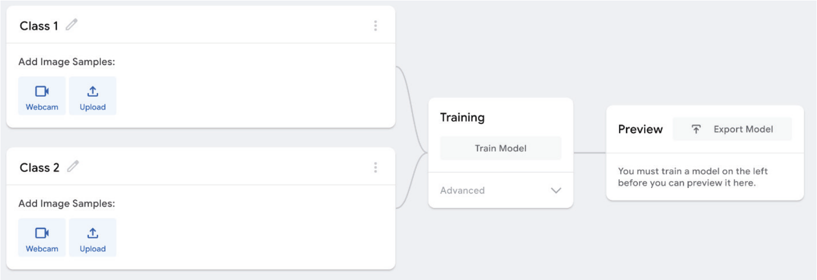
Note. Figure 4a shows students' initial designs feature worksheet-based rug patterns; Figure 4b shows the digital transformation of patterns using pixelation widgets and quilt generators; Figure 4c demonstrates a completed quilt blocks that represent the iterative design process; and Figure 4d shows a small weaving loom.

Leveraging Research and Critical Thinking Skills to Critically Engage Students with Computing

Teachers introduced machine learning, neural networks, and algorithmic bias through the CRC lessons to help students develop technical and critical perspectives on computation. For example, by incorporating interactive AI-based activities, teachers encouraged students to engage with AI as both users and critical thinkers, fostering computational literacy alongside ethical considerations. For instance, Teacher C used Google Quick Draw (Jongejan et al., 2017) to introduce machine learning and pattern recognition in his classroom. Students sketched characters, symbols, and geometric patterns, allowing them to explore how an AI model processes and categorizes visual inputs. As students contributed their drawings, the AI neural network attempted to predict and refine its understanding of the images, demonstrating how machine learning models evolve based on user input. This interactive, gamified approach made AI concepts accessible and provided a tangible way for students to understand model training and data-driven learning processes. Expanding on this foundation, Teacher E integrated AI concepts into a lesson on algorithmic bias and ethical considerations in AI systems. Using Teachable Machine (Google, 2019), students explored how facial recognition software operates and examined biases embedded in AI models (Figure 5). The lesson began with students studying facial recognition technologies, prompting students to analyze how AI can reflect societal biases based on training data. Students collected and uploaded categorized images of individuals in different professions to explore these biases further, training the Teachable AI system to recognize patterns. Through this experiment, students discovered discrepancies in AI classification and discussed the ethical implications of biased training data. Later, Teacher E embedded additional research skills in another lesson on bias in AI. This lesson cultivated students' critical awareness of algorithmic bias, specifically regarding the underrepresentation and misrepresentation of Navajo culture. Students explored real-world examples of AI systems exhibiting bias and analyzed the nature of the interpretation of Navajo culture within these algorithms. Through exploring these different real-world cases, Teacher E's lesson helped students' understanding of AI bias and develop research and critical thinking skills.

Figure 5

Teachable Machine for AI

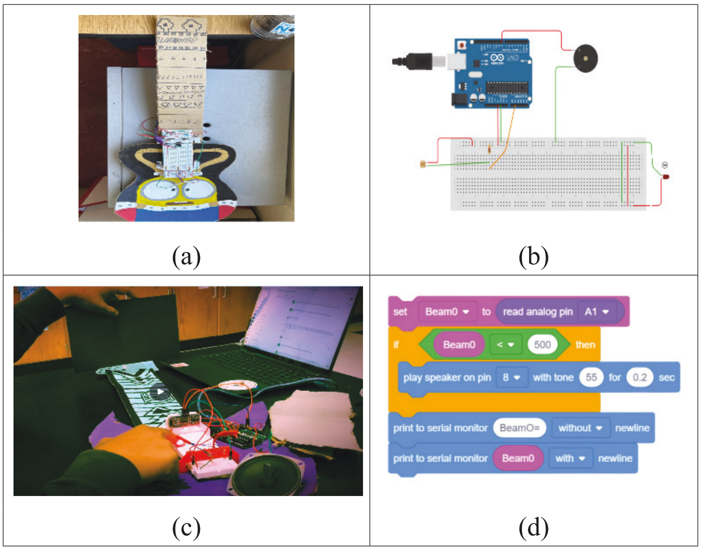


Note. Students engaged with Teachable Machine to explore AI training, facial recognition, and algorithmic bias. The image shows how they collected and uploaded categorized images, trained the AI model, and analyzed its accuracy and biases.

Additionally, teachers guided students to explore all computing engagements through an Indigenous cultural lens using research-based approaches. For example, Teacher D designed an inquiry-driven lesson where students built a laser guitar using TinkerCad (Autodesk, 2011), Arduino (Arduino, 2003) components, cardboard, glue guns, and paint (Figure 6). Before constructing their instruments, students researched traditional Indigenous designs to inform the design and sound of the instruments. They also explored traditional Indigenous music, decoded song rhythms into computational sequences, and uploaded these coded rhythms into the Arduino system, reinforcing the intersection of computing, music, and cultural expression.

Figure 6

Laser guitar and computing



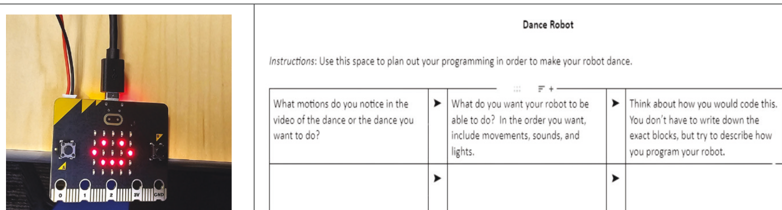
Note. Figure 6 illustrates how research skills became relevant to CRC education through iterative design and cultural exploration. Figure 6a represents the laser guitar, 6b represents the Arduino system, 6c represents the guitar connected to the Arduino system, and 6d shows a part of the block-based code for the project.

Reflection, Refinement, and Professional Growth through Ongoing Collaboration

As described above, all seven teacher fellows engaged in sustained CRC PD and iteratively refined their lesson plans to align them with students' culture, personal interests, and skills across multiple projects. Here, we illustrate teacher professional growth through their pedagogical approaches in response to student observation and feedback, personal reflection on experimentation with the computing tools, and discussions with peers. For instance, Teacher G expanded the Micro:bit Robotics Dance project by introducing reflective journaling (Figure 7), where students documented their learning process and how the coding of robotic dance movements connected with actual movements. This proved to be a valuable addition, allowing students to document their coding decisions, challenges, and personal connections throughout the project, strengthening their computational thinking and connection to Indigenous traditions.

Figure 7

Micro-bit and Students' Decoding Worksheet



(a) (b)

Note. Figure 7a shows a micro:bit students coded to display pet names and Figure 7b shows the instructions students followed to program the micro: bit robots to perform traditional dances.

Similarly, Teacher A adjusted the Sphero A-Maze-ing Traditional Trails lesson by incorporating storytelling and movement. Students coded the Sphero and narrated its journey through Hopi-inspired landscapes, thereby strengthening computational and linguistic connections and establishing connections between code and movement. She found students to respond positively to these changes. Teacher B initially designed the Micro:bit and Indigenous Languages lesson to teach students to encode Hopi phrases into Micro:bit to reinforce Navajo learning through technology. However, just encoding phrases removed the phrases from their contextual use in the community. Teacher B modified the lesson plan asking students to interview family and community members and incorporate culturally significant Hopi phrases. This change supported students' contextual learning of phrases that are meaningful to their community and added a personal touch through the Micro:bit display while reinforcing the role of technology in supporting the preservation of the Hopi language. The other teachers, too, made significant refinements to the lesson plans. Teacher E modified the Bias in AI lesson to include student-led case studies, where students researched and presented real-world examples of AI bias, fostering deeper critical engagement. Teacher D elaborated the e-Textiles project to include a maker portfolio, where students documented their design decisions, coding logic, and reflections on how their wearable designs connected with their personal or cultural identity. Through these refinements, the teachers demonstrated an awareness of the need for collaborative and peer learning, the relevance of computing within their cultural context, and the need for learners to embody code through movement, dance, et cetera, strengthening their understanding to computing.

Discussion board contributions underscored the importance of ongoing collaboration in professional growth. As teachers shared insights on lesson implementation, exchanged troubleshooting strategies, and provided peer feedback on best practices for engaging students with culturally relevant computational activities, they refined the lesson plans. For example, Teacher F commented on Teacher E's lesson, how students working on Quick Draw projects could be a great introduction to data science since it collected data from people who completed the prompts and used AI to create groups based on similarities. Teacher D confirmed that her students would appreciate Teacher E's lesson, especially learning how Quick Draw collects image and sound data, breaking them into little snippets that can then be used to train the model. Students can choose items to train on. Later, Teacher D further elaborated on how maintaining community buy-in, especially among elders and leaders, was just as crucial for these lessons. Developing trust and relationships was just as important as the computation. These relationships allow for sustainable computing education projects to carry on in the future and encourage the local communities' support. These teacher interactions highlight the significance of reflection and refinement through ongoing collaboration, emphasizing how shared insights contributed to lesson plan refinement. As teachers iteratively refined their CRC lessons by exchanging feedback and troubleshooting strategies to engage students better, they refined instructional approaches, developed a better understanding of what works in their context, and strengthened the cultural and community relevance of computing lessons, making them more impactful and inclusive.

DISCUSSION

This study examined how experienced CS teachers developed computing curricula while participating in a sustained CRC PD program. Using a data fusion analytic approach, we identified three key themes that emerged from Indigenous-serving teachers' learning processes and analyzed how these themes were reflected in their designed curriculums. Our findings offer valuable insights and best practices that can inform CS education research and support Indigenous-serving educators in designing CRC curricula.

Teacher Professional Growth

A key outcome of this CRC PD was the development of pedagogical skills among teacher fellows, aligning with the ITPMG's four interconnected domains that shape teachers' professional trajectories through iterative cycles of reflection and enactment. Our findings illustrate how sustained PD facilitated shifts across these domains, particularly in how Indigenous-serving CS teachers integrated research-based instructional strategies into their lesson planning and instruction. Teachers refined their instructional approaches by understanding the best ways to infuse computing into students' culture, engaging in iterative design cycles, and fostered meaningful community involvement to enhance learning. They refined their curricula through collaborative reflection to better align with student experiences, reinforcing the finding that CRC fosters inclusive, meaningful CS education. Therefore, in response to our research questions, we find that teachers created opportunities for community connections, leveraged critical thinking, and engaged in collaborative reflection and refinements to develop CRC curricula, leading to meaningful changes in teaching and learning. These findings support existing research in teacher development (Dikilitaş, 2015; Laudonia et al., 2018; Ni et al., 2022; Searle et al., 2023; Wilson et al., 2023). From a theoretical perspective, the external domain (PD training and resources) facilitated foundational knowledge in pedagogical strategies, influencing changes in the personal domain (teachers' evolving pedagogical beliefs). We observed these shifts in the domain of practice as teachers situated the lessons on the local culture to make the lessons relevant, with the domain of consequence (student learning outcomes and engagement) emerging as a key area for future exploration. Teachers' growth across these domains helped them design and implement robust and inclusive lessons for the students while fostering stronger community connections. These findings can be extended to other contexts to promote transformative learning experiences across diverse student populations. The findings are also relevant to the following topics in CRC research.

Teachers Bridging Indigenous Culture and Computing

All participating teachers integrated CRC into their lesson planning by designing learning engagements that encouraged students to engage with CS concepts through the creation of culturally meaningful artifacts, such as the animation of traditional conversations in local language, woven rugs, and musical instruments. This approach aligns with research emphasizing the importance of designing artifacts as the context for learning in STEM education (Guzey et al., 2014; Jayathirtha & Kafai, 2020; Lui et al., 2024), underscoring the promise of our findings in promoting CRC within Indigenous communities. However, despite successfully incorporating design-based lessons, teachers faced challenges accessing Indigenous cultural resources. Non-Indigenous teachers, in particular, expressed the need for additional guidance and materials to ensure their lesson plans were both culturally responsive, contextually relevant, and high quality. Prior research highlights non-Indigenous educators' challenges in embedding Indigenous perspectives into their teaching (Jin, 2021). Although this paper provides evidence that collaborative PD models, including consistent peer discussions and partnerships with Indigenous communities, can help address these challenges, we recognize the need for specifically designed PD and PLCs to support non-Indigenous teachers (Yan et al., 2025). Additionally, collaborations with local elders and Indigenous knowledge experts can strengthen the authentic integration of computing into local culture. By adopting these strategies, teachers can ensure that computing education is both inclusive and meaningful.

Supporting Computational and AI Knowledge in Indigenous Communities

Computational activities like storytelling and dance were celebrated within Indigenous communities as means of cultural expression and engagement with technology. These lessons demonstrated how computation can be a modality of Indigenous cultural expression and a medium of engagement for the young creators, their mentors, and the community at large. However, there was also concern about the ease with which cultural assets such as design patterns and artwork can be digitally transmitted, underscoring the need for trust-building between educators, learners, and communities. Collaborative discussions on digital ethics and community-driven guidelines for sharing cultural knowledge are indeed essential to safeguard intellectual property and data sovereignty in computational contexts. In contrast, GenAI received less enthusiasm from teachers, learners, and the community. The one lesson plan that successfully addressed AI literacy and bias prompted discussions on how algorithms can reflect systemic inequalities and exclude Indigenous voices, but its resonance was limited. Understanding and using GenAI is crucial for Indigenous communities, given its profound implications for cultural preservation, intellectual property, and data sovereignty. Research indicates that GenAI often reinforces biases and stereotypes while posing threats to cultural and intellectual property (Worrell & Johns, 2024). Moreover, AI algorithms have frequently been found to overlook underrepresented communities, leading to exclusionary outcomes (Salas-Pilco et al., 2022).

These challenges highlight the need for educators to critically engage with AI education adopting culturally responsive teaching practices. Overall, CRC must encompass building both computational and AI literacy in communities. By learning to design and control AI tools, community members can advocate for ethical AI development that respects Indigenous knowledge systems, including those that can be shared and digitized through computation. Integrating computing and AI literacy into school curricula can help students become active participants in the development of these tools with greater inclusivity and fairness. We further recommend that educators explicitly teach Indigenous data sovereignty, facilitate critical conversations on computing and AI ethics, and encourage students to explore how their perspectives can shape the field. Initiatives such as the AI For Good Foundation and the Indigenous AI Alliance provide training programs and curriculum materials to support the integration of AI education in Indigenous-serving schools. Participation in professional development workshops led by these organizations can empower teachers to bring AI education into their classrooms in a manner that is both inclusive and culturally sensitive, ensuring that AI literacy aligns with Indigenous values and priorities.

Implications for Future Practice and Research

Teaching computer science in Indigenous communities presents unique challenges, particularly in aligning instruction with cultural perspectives and providing equitable access to computational learning opportunities (Smith et al., 2022). This paper identifies key implications for computer science instruction in Indigenous-serving schools. First, incorporating designinfused learning into CS curricula can help students connect computing concepts with their culture (Davis, 2024). All teachers in this study integrated design elements into their lesson plans, demonstrating how CRC can be effectively woven into CS instruction. Second, teachers should be encouraged to explore new technologies that are relevant to Indigenous communities, including AI and other emerging computational tools. The teachers in this study demonstrated a willingness to integrate new technologies into their instruction, indicating that Indigenous-serving schools are receptive to innovative CS education approaches. To support teachers serving Indigenous and other underserved communities, the wider teacher education and learning research community must co-develop targeted resources and build on each other's successes. Finally, school communities must give students consistent opportunities to showcase their projects at cultural events and school-wide presentations (Brown, 2021). This engagement with community traditions can enhance students' sense of belonging in computing while fostering a deeper appreciation for how computing intersects with their cultural heritage. To support such showcases, collaborations with district and state-wide departments and industry partners can be productive. Organizations such as Zero Robotics, Rover Observation, and Discoveries in Spaces come to mind. Future research should explore how CRC-informed instructional approaches evolve over time and assess their impact on student learning outcomes. Leveraging data fusion methodologies can provide deeper insights into teacher learning trajectories and the broader effects of professional development in CS education. Our future work will focus on how teachers implement these lessons in their classrooms and their influence on students' understanding of computing concepts. Additionally, examining learning outcomes after the integration of culturally relevant curricula will offer a clearer picture of their effectiveness. Researchers can further utilize data fusion techniques to analyze the professional growth of in-service CS teachers, offering a more comprehensive perspective on the role of PD in fostering culturally responsive computing instruction.

LIMITATIONS

This study illustrates how teachers blend pedagogical and computational skills in CS education; however, further research is needed to evaluate the effects of these changes on student learning, persistence, and interest. While our findings robustly demonstrate teacher growth in research-driven lesson planning, they do not fully capture direct student outcomes. Future work should assess how students engage with CRC curricula, examining computational thinking, problem-solving abilities, and personal identification with computing, as well as explore how sustained PD and mentorship influence the professional trajectories of Indigenous-serving CS educators. Deepening our understanding in these areas can enhance support for culturally and contextually relevant CS education.

A few limitations should be considered when interpreting these findings. First, the design and cultural relevance of discussion prompts, and reflection questions may have influenced the themes identified through topic modeling and qualitative analysis. Prompts that are leading or unbalanced might skew responses, amplifying some themes while underrepresenting others. Future studies should develop prompts that encourage diverse and unbiased reflections, ideally co-created with Indigenous educators to authentically align with CRC perspectives. Second, the study's small sample size of seven teachers, while allowing for detailed analysis, limits the generalizability of the findings. Although the insights provided are rich, they may not represent the broader context of Indigenous-serving schools. Future research should involve larger and more diverse teacher cohorts across multiple Indigenous communities, enabling comparisons of CRC implementation across different cultural, linguistic, and geographical settings.

Finally, while our findings suggest that CRC-based lessons foster stronger engagement and computational thinking among Indigenous students, further research is needed to assess how these instructional strategies translate into measurable student learning gains, long-term retention, and pathways into computing. Longitudinal studies tracking teacher growth and student progress will provide a more comprehensive understanding of the impact of CRC in Indigenous-serving computing education. By acknowledging these limitations, future research can refine methodological approaches, expand data collection, and strengthen the evidence base for CRC's role in broadening participation in computing for Indigenous communities.

CONCLUSION

This study advances research on CRC by examining how Indigenous-serving CS educators, particularly those working with Indigenous students from the Hopi, Navajo, Pueblo and Apache communities of the Four Corners region, design and implement CRC curricula. Through data fusion, we identified three themes, highlighting how sustained PD supports the integration of Indigenous culture and computing education. This paper contributes to the broader literature on computing education for Indigenous students, offering guidance on CRC curriculum development and pedagogical strategies for educators in Indigenous-serving schools. These insights can inform policies and professional development initiatives, helping to bridge systemic gaps in CS education and increase Indigenous student participation in computing fields. By positioning computing as a tool for cultural expression, knowledge preservation, and innovation, this research highlights the potential of CRC to broaden participation in CS, enhance digital equity, and support Indigenous students in navigating pathways into computing careers. Future efforts should continue refining CRC-based curricula, expanding teacher training programs, and investigating long-term student outcomes, ensuring that computing education remains inclusive, culturally sustaining, and responsive to the needs of Indigenous communities.

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