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ORIGINAL PAPER

Pre–service Teachers Computational Thinking (CT) and Pedagogical Growth in a Micro–credential: A Mixed Methods Study

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Abstract
Teacher preparation programs are essential to ensure pre–service teachers are equipped with the skills and knowledge necessary to teach in the PK–12 learning environment, but are rooted in a traditional paradigm of a compacted curriculum with little room for more content. The addition of Computational Thinking (CT) becomes one more thing to add to a packed schedule and integration of CT into established courses takes major redesign of courses. One university in Maryland, U.S. developed a CT focused micro–credential for K–8 pre–service and in–service teachers. In examining pre– and post–content surveys, reflection journal entries and lesson plans, pre–service teachers report CT and pedagogical content growth in their awareness and integration of CT in their lives and future classrooms. Results indicate a CT micro–credential could be an innovative solution to adding CT content to an over–packed, pre–service curriculum. In addition, CT micro–credential courses increased pre–service teachers' knowledge and self–awareness to the feasibility to proficiently implement CT across all courses.

Keywords Competency–based · Computer science · Computational thinking · Micro–credentials · Pre–service teachers · Teacher education

Introduction

In today's pre–service education landscape there is never enough time to prepare students in everything they need to know prior to entering the K–12 teaching workforce (Yadav et al., 2017; Zha et al., 2020). Pre–service higher education systems are entrenched in a traditional paradigm that leaves little room for new content. In 2018, the Maryland State Department of Education approved computer science (CS) standards for K–12 classrooms, creating more opportunities for students while also creating more learning requirements in an already packed pre–service curriculum (Maryland State Department of Education, 2018). Innovative systems were needed to provide pre–service teachers with the experience and knowledge of CS standards prior to entering the K–12 classroom. One university in Maryland, U.S., decided to tackle this issue by developing online micro–credentials for computational thinking (CT), a thinking process embedded in CS (CSTA, 2017) and encompassing four of the seven core practices of CS (K12 Computer Science [CS], n.d., Core Practices image), for K–8 pre–service and in–service teachers. This study investigated the effectiveness and impact of these micro–credentials for pre–service teachers using a mixed methods convergent design.

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Literature Review

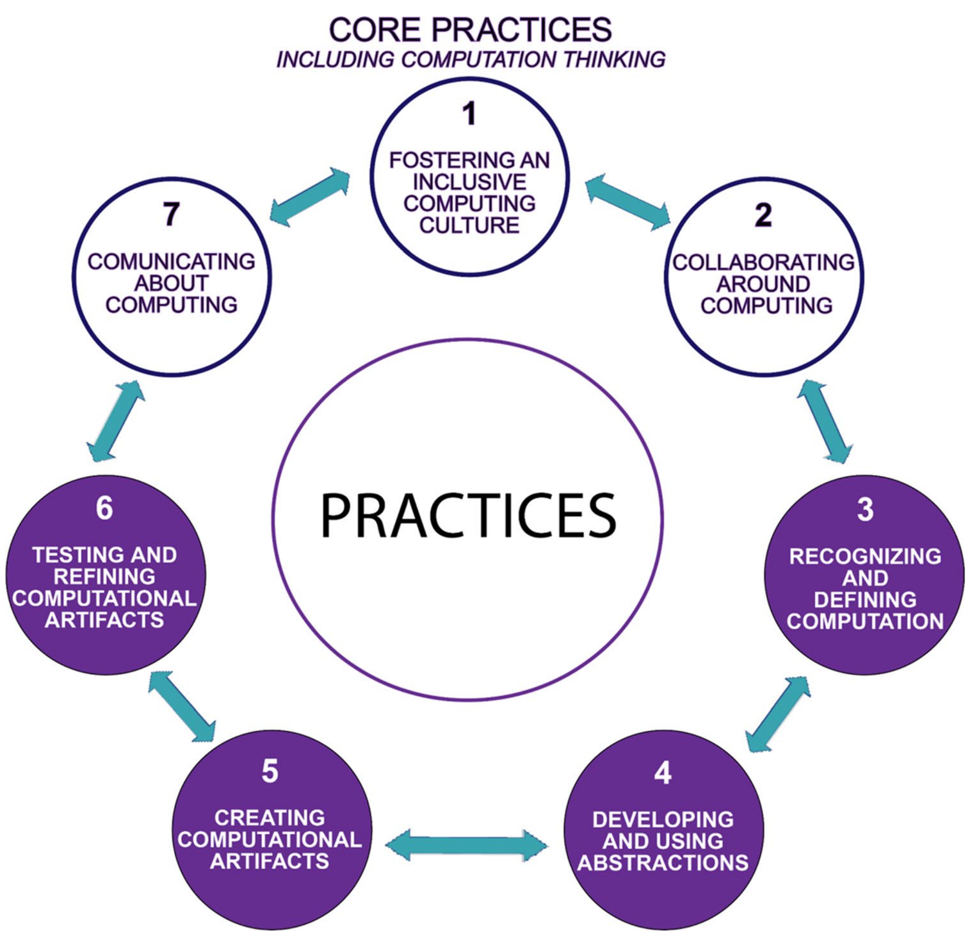
Computational Thinking

CT is a process utilizing CS strategies to break down complex tasks in a systematic manner typically computer generated (Wing, 2006). Aho (2012) simplifies CT as a thought process that involves formulating problems, wherein "their solutions can be represented as computational steps and algorithms" (p. 832). This thinking process involves breaking down a problem into specific steps and following those steps to a solution. Firstly, the solution is determined, then, it is tested and refined. This process is usually done through the lens of computer systems but can and should be conducted outside of digital and computing landscapes, known in CT as “unplugged approaches” (K–12 Computer Science [CS] Framework, 2016, p. 69).

Four Core Practices of CT

CS has seven core practices that support students’ computational literacy (K–12 CS Framework, 2016). Of these seven core practices, the four main practices: (3) “recognizing and defining computational problems,” (4) “developing and using abstractions,” (5) “creating computational artifacts” and (6) “testing and refining computational artifacts,” are CT practices (see Fig. 1). Recognizing and defining computational problems involves decomposition, the breakdown of large problems or concepts into smaller pieces, where the learner should identify the problem, decompose that problem and determine if the problem can be solved computationally (K–12 CS Framework, 2016). Developing and using abstractions includes pattern matching and viewing the big picture of the problem to better understand the interactions of the elements and how previous solutions could be modified for the presented problem(s) (K–12 CS Framework, 2016). Creating computational artifacts integrates creativity with iterative design through planning and creating an original or modifying an existing product (K–12 CS Framework, 2016). Testing and refining computational artifacts is the step in which the product is tested for refinement and evaluation (K–12 CS Framework, 2016). These practices are combined and viewed through a computational lens to create a problem–solving process for global solutions but more support is needed for pre–service teachers’ preparation to integrate these core practices of CT into their future classrooms.

Fig. 1 Computer Science Core Practices including Computational Thinking image. *Note.* Adapted from K12 Computer Science Framework (p. 68), 2016, K12 CS (https://k12cs.org/wp-content/uploads/2016/09/K%E2%80%9312-Computer-Science-Framework.pdf). CC BY-NC-SA 4.0. Adapted with permission



Note. Adapted from *K12 Computer Science Framework* (p. 68), 2016, K12 CS (https://k12cs.org/wp-content/uploads/2016/09/K%E2%80%9312-Computer-Science-Framework.pdf). CC BY-NC-SA 4.0. Adapted with permission.

Pre–Service Education

Teacher preparation programs must prepare pre–service teachers with the skills needed to teach CT in K–12 environments. While most teacher programs provide an overview of CT in their methods and technology courses, there is not enough time to cover the concepts besides the typical coding lesson and the CS framework. Therefore, pre–service teachers need more instructions to learn how to integrate CT into their lessons (Mason & Rich, 2019; Selby, 2015; Yadav et al., 2017).

To address this problem, teacher educational programs and professional development programs are embedding CT into existing courses and creating short modules to teach the applicability of CT as a problem-solving framework into other disciplines besides computer science (Blum & Cortina, 2007; Bouck et al., 2021; Prieto–Rodriguez & Berretta, 2014; Yadav et al., 2014, 2017). The literature suggests that the exposure to the modules increased pre–service teachers' pedagogical knowledge and positive attitudes for teaching CT in other domains but more empirical research is needed and pre–service teachers need more support beyond these short opportunities (Bouck et al., 2021; Mason & Rich, 2019). A possible solution for the need of more support is CT micro–credentials for pre–service teachers.

Micro–Credentials

Micro–credentials are small, competency–based learning courses for personal or professional growth with feedback opportunities, usually from a facilitator or enrolled peers (DeMonte, 2017; Gamrat & Bixler, 2019). Although micro–credentials can be designed for face–to–face, online, or hybrid environments, the increase of online learning and the shift to remote learning due to the COVID–19 pandemic facilitates the need for online micro–credentials. Articles on the design and development of micro–credentials are abundant but empirical evidence of micro–credential and microlearning design and effectiveness is limited (Burton–MacLeod & Carliner, 2020; Zhang & West, 2020). This article showcases the use of an online micro–credential for pre–service teachers' CT and pedagogical growth.

Methods

This study investigated the effectiveness and impact of CT micro–credentials for pre–service teachers, utilizing a mixed methods convergent design, collecting qualitative and quantitative data simultaneously, analyzing the data separately and merging the results and interpretation (see Creswell & Clark, 2018, Fig. 3.4, p. 70) to answer the overarching research question (RQ), How does a micro–credential support pre–service teachers' CT and pedagogical comprehension and planning for their future classroom? Two sub–research questions (RQ1 and RQ2) were included to further guide this central question:

1. To what extent and in what ways do pre–service teachers' reflections and lesson plans contribute to a more comprehensive understanding of their CT knowledge performance in a pre– and post–content survey?
2. To what extent and in what ways do pre–service teachers' reflections contribute to a more comprehensive understanding of their pedagogical knowledge performance in a pre– and post–content survey?

Micro–Credential Design

Three online, asynchronous micro–credential courses were developed in Spring 2020 on the topic of CT through a state level grant to support pre–service and in–service teachers. Each course included five modules, for a total of 15 modules, scaffolding the content of the course in more manageable chunks. These were designed to be instructor facilitated, self–paced and competency–based, completed in about 15 hours and support pre–service and in–service educators in their knowledge and integration of CT in their classroom. Facilitated courses include an instructor who guides the learners in their learning. There were three facilitators who were given already designed courses and provided feedback to the learners on their submissions. These facilitators were K–8 teachers who had experience in CS and CT and were trained on facilitating micro–credentials and competency–based learning by the lead researcher. Finally, holding true to a micro–credential, these courses were designed to be competency–based, meaning if learners did not meet the competency to complete the course or gain the credential, then they could resubmit the needed work, after facilitator feedback, to show their competency of the content. This resubmission process can occur as many times as needed, each with more feedback and guidance from the instructor, until competency is met.

The stack of courses, when taken together, leads to competency in CT knowledge and practices. The first course, CT Basics, focused on the foundational aspects of CT and CS, including the core practices of CT and unplugged and digital coding (see Fig. 2). In this first course, participants engaged in CT activities, both digital and non–digital (unplugged), relating those activities back into their current or future classrooms through reflection and critical analysis of their work. The second course, Pedagogical Approaches to CT, focused on the pedagogy and teaching/learning strategies associated with CT (see Fig. 3). In this second course, the participants critically analyzed CT lessons and reflected on the inclusion of these lessons in their current or future classrooms through pedagogies and strategies such as active learning (Brame, n.d.), the 4Cs of twenty-first century learning (communication, collaboration, critical thinking

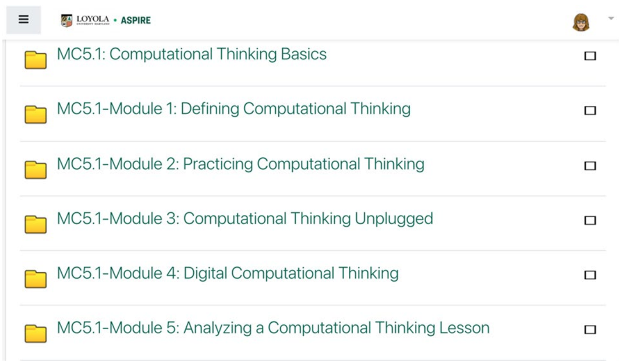


Fig. 2 Micro-credential Course 1: CT basics

and creativity; Common Sense Education, 2016), persistence and resilience (Shechtman, n.d.), Bloom's Taxonomy (Center for Teaching Vanderbilt University, 2016) and the relevant K–12 standards (CSTA, 2017; ISTE, n.d.). Finally, course three synthesized the previous two courses, focusing on teacher– and student–centered instruction, growth mindset in CT and the Understanding by Design (UbD) framework (McTighe & Wiggins, 2012; see Fig. 4). In course three, the micro–credential wrapped up with a culminating lesson plan (LP) using the UbD framework. In this LP, participants created a CT–integrated lesson for their current or future classrooms, identifying and critically analyzing the core practices of CT and the pedagogy and teaching/learning strategies included in their lesson.

Participants

The participants of this study, pre–service teachers in the summer of 2020 ($n=10$), are a subgroup of a larger population of pre–service and in–service teachers ($N=82$) who were enrolled in the three micro–credential courses in the Summer of 2020. This larger population of pre– and in–service

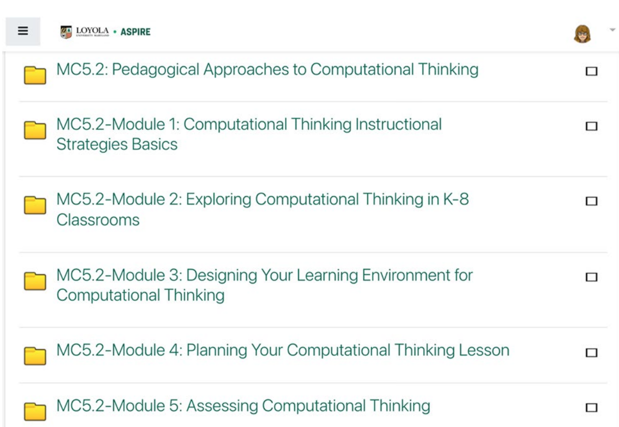


Fig. 3 Micro-credential Course 2: Pedagogical approaches to CT

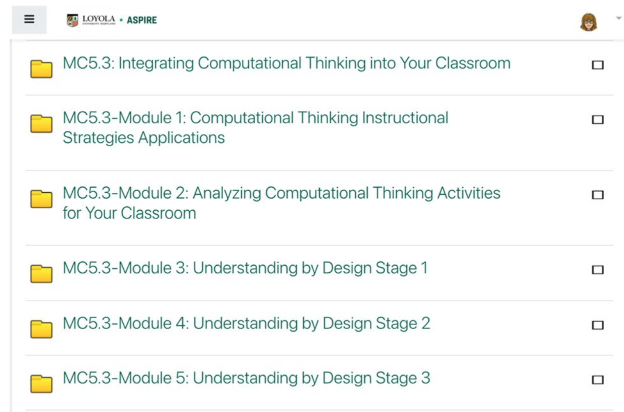


Fig. 4 Micro-credential Course 3: Integrating CT into your classroom

teachers were selected from a convenience sample of pre–service and in–service teachers from the participating institute of higher education and a partnering local school system. Of this population, 17 participants (20.7%) were pre–service teachers enrolled in a pre–service undergraduate or graduate education program at the participating institute of higher education in Maryland in the summer of 2020. Of these 17 pre–service teachers enrolled in the micro–credentials, 11 (64.7%) completed the three courses and of those 11, ten (58.8%) consented to participate. Thus, this study will focus on the data collected from these ten consenting, pre–service teachers who completed the micro–credential courses.

Data Sources

Over the three micro–credential courses, various data was collected as part of the course content (see Table 1). Identical pre–and post–content surveys were used to measure the participants' CT and pedagogical knowledge before and after the content. A reflection journal (RJ) was created and used with 16 distinct journal entries. Journal entry 16 was used for RQ2 only. LPs integrating CT were also created by the participants and submitted as one of the final projects in the micro–credential courses.

Instrument Construction

The pre– and post–content surveys were developed by the lead researcher and included 30 questions covering CT and pedagogical concepts. Within both concepts, five process objectives were focused on to support the cognitive processes of the learners (Thorndike & Thorndike–Christ, 2010). These five process objectives were (1) recognizes terms and vocabulary, (2) identifies principles, concepts and generalizations, (3) analyzes principles, concepts and generalizations, (4) evaluates principles, concepts and generalizations and (5) applies principles, concepts and

Table 1 Data sources with number of participants and research question alignment

Data source	Number of accessible artifacts	Research question alignment	Data analysis
Pre-content survey	10	RQ1 and RQ2	Paired *t*-tests
Post-content survey	10	RQ1 and RQ2	
CT and pedagogical content reflection journal entries 1–15	8[a]	RQ1 and RQ2	In Vivo (1st cycle) Pattern Coding (2nd cycle)
Reflection journal entry 16	8[a]	RQ2	Provisional Coding
Lesson plans	10	RQ1	Provisional Coding

[a] Two participants' reflection journals were not accessible by the lead researcher. See limitations section for more details

generalizations. Within these five process objectives, CT and pedagogical concepts were aligned with a mix of true/false, multiple choice and scenario–based questions, assessing participants' knowledge and application of CT and pedagogy in teaching CT, including assessments for CT (see Table 2). These questions were sent to four experts to validate the surveys. Two of the experts were university professors, one in Educational Technology and one in CS and two of the experts were K–8 educators in computer and technology education. They reviewed content and key checks as suggested by Haladyna (2004), providing feedback on the questions including clarity of wording and reviewing answers for accuracy prior to implementation with the participants.

The RJ prompts and LP templates were created by the lead researcher and K–8 educators in computer and technology education. An RJ template was created in Google Slides so learners could make a copy and complete the provided prompts in a personalized copy of the RJ. The RJ template included 16 distinct journal entries, one for each module in each course (entries 1–15) and one final, reflective entry on all three courses (entry number 16), which were designed over 30 slides (see Fig. 5 for an example of the RJ slides from course two). Each journal entry was aligned to content in the corresponding module, providing opportunities for the pre–service teachers to reflect on their learning and consider their future classroom within the module content. The RJs were submitted in the first module of course one, and the facilitators regularly reviewed the RJs throughout the course, providing feedback, encouragement and clearing up misconceptions in each module. The UbD framework (McTighe & Wiggins, 2012) was used as a template for the design of the LPs. The RJ prompts and LP template were reviewed for content validity prior to use with participants by two university professors, one in Educational Technology and one in CS, providing feedback on wording, clarity and connection back to the course content, as recommended by Guerra–López (2008),

Data Collection

The data was collected between June 2020 and September 2020. The pre– and post–content surveys were conducted in Qualtrics with the link available in the learning management system (LMS) as an activity for the participants to complete within the micro–credential courses. The pre–content survey was administered during the first module of the first course and a post–content survey was administered during the last module of the last course. The RJ template was available in the first module of the first course and was to be completed during each module of the three courses. The participants submitted their RJ templates with comment access in the first module of the first course in the LMS. The ongoing RJ entries were completed by participants throughout the courses with one entry per module for a total of 16 distinct journal entries. The LP template, in Google Documents form, was provided to participants in the third module of the third course in the LMS through a forced copy link. The completed LPs were submitted in the LMS in the fifth module of the third course. Any support in making a copy or using Google was provided to participants through the facilitators.

Data Analysis

With the mix of data sources, different quantitative and qualitative analyses were conducted with the data.

Quantitative Analysis

The demographic data was analyzed through frequency counts and the pre– and post–content survey data ($N=10$ for both) were analyzed through paired *t*–tests using statistical software (see Table 1 for data sources and number of accessible artifacts).

Qualitative Analysis

Reflection journal entries 1–15 ($N=8$) were analyzed inductively with a first– and second–cycle coding method (Saldaña, 2021). RJ entries 1–15 were read in entirety prior to coding. In Vivo coding was used for the first–cycle coding, extracting participant quotes from the RJ prompts (Saldaña, 2021). The second–cycle coding method used

Table 2 Pre- and post-content survey concepts and sample questions

Process objectives	CT concept	CT sample question	Pedagogical concept	Pedagogical sample question
Recognizes terms and vocabulary	Specific CT Vocabulary	True/False: Computational Thinking is a problem-solving process utilizing analytic and methodological approaches	Specific Pedagogical Vocabulary	Multiple Choice: What are the 4Cs? A. Communication, Collaboration, Critical Thinking, & Creativity B. Computational Thinking, Creative Problem Solving, Competence, Completion C. Computing, Coherence, Comparisons, Completion D. Clear, Concise, Concrete, Correct
Identifies principles, concepts, and generalizations	Core Practices of CT	Multiple Choice: What are the 4 main methods of computational thinking? A. Decomposition, Pattern Recognition, Abstraction, Algorithm Design B. Problem-solving, Persistence, Patience, Communication C. Identifying, Analyzing, Generalizing, and Solving D. Organization, Analysis, Representation, Implementing Solutions	Pedagogies in Teaching CT	True/False: CT includes various concepts, practices, and perspectives, so assessing a student with regards to only one of these aspects provides an incomplete picture of that learners' CT skills
Analyzes principles, concepts, and generalizations	Connecting Core Practices of CT to Practice	Multiple Choice: When faced with a large problem, which method of CT should be first utilized to support perseverance? A. Decomposition B. Pattern Recognition C. Abstraction D. Algorithm Design	Connecting Pedagogies to Practice	Multiple Choice: How can a teacher support failure in the classroom? A. Model failure within their own work B. Scaffold the work so students are successful C. Utilize summative assessments D. Communicate with parents when students fail
Evaluates principles, concepts, and generalizations	Analyzing Examples through CT Principles	Scenario: Students read a story. They then select a character from the story that is most like them and use text-based evidence to support the comparison. They then create a comparison chart with their data From this scenario, which sentence best represents Developing and Using Abstractions? A. Students read a story B. They then select a character from the story that is most like them and use text-based evidence to support the comparison C. They then create a comparison chart with their data	Analyzing Pedagogical Practices for CT	Multiple Choice: Which of the following is an appropriate way to formatively assess computational thinking? A. Feedback on a graded coding activity B. Grades on a weekly CT Vocabulary Test C. Weekly feedback in a persistence reflection journal D. Using a rubric for a final project

Table 2 (continued)

Process objectives	CT concept	CT sample question	Pedagogical concept	Pedagogical sample question
Applies principles, concepts, and generalizations	Applying CT Principles	Multiple Choice: Identify the CT principle for each statement: Learners conduct a survey and collect data A. Recognizing & Defining Computational Problems B. Testing and Refining Computational Artifacts C. Developing & Using Abstractions D. Creating Computational Artifacts	Applying Pedagogical Approaches	Multiple Choice: Identify the best assessment approach for each statement: Students share their data analysis for peer-review A. Formative B. Summative

Pattern coding, categorizing the In Vivo codes into similar groups (Saldaña, 2021). These categories were then themed through the lens of the RQs. Intercoder agreement through discussion of the In Vivo codes, categorization of those codes through Pattern coding and final identified themes was used to establish the reliability of the thematic analyses (Creswell & Poth, 2018). After the first cycle coding method, the researchers discussed the codes and checked their processes before moving to the second–cycle code. After the second cycle coding, the researchers discussed the categories and came to an agreement on the themes found in the data.

Reflection journal entry 16 ($N=8$) was analyzed deductively through Provisional Coding, transforming the text responses into frequencies, based on pedagogical and CT content categories (Grbich, 2007; Saldaña, 2021). The participants' LPs ($N=10$) were also analyzed deductively using Provisional Coding to transform the textual lesson elements into numeric counts based on the four core practices of CT (see Fig. 1; K12 CS, n.d.; Saldaña, 2021). Intercoder agreement through discussion of the codes and categorization of those codes in the pedagogical and CT content constructs (RJ entry 16) and the four core practices of CT (LPs) was used for these codes to establish the reliability for accurate frequencies (Creswell & Poth, 2018).

Merging of the Results and Interpretation

After the data was analyzed based on the quantitative or qualitative method, the results were synthesized for a more comprehensive understanding of how a micro–credential supports pre–service teachers' CT and pedagogical knowledge and planning for their future classroom (Creswell & Clark, 2018).

Positionality

The researchers have various positionalities and backgrounds in this research with varying knowledge of CT, CS, K–12 education and teacher education. The lead researcher also has knowledge in micro–credentials and supported the design of these CT micro–credentials. Our experience in CT, CS, K–12 education, teacher education and micro–credentials positioned us well to conduct this study.

Results

Demographics

The participants ($N=10$) were all pre–service teachers with a range of interests in grade level and subject area (see

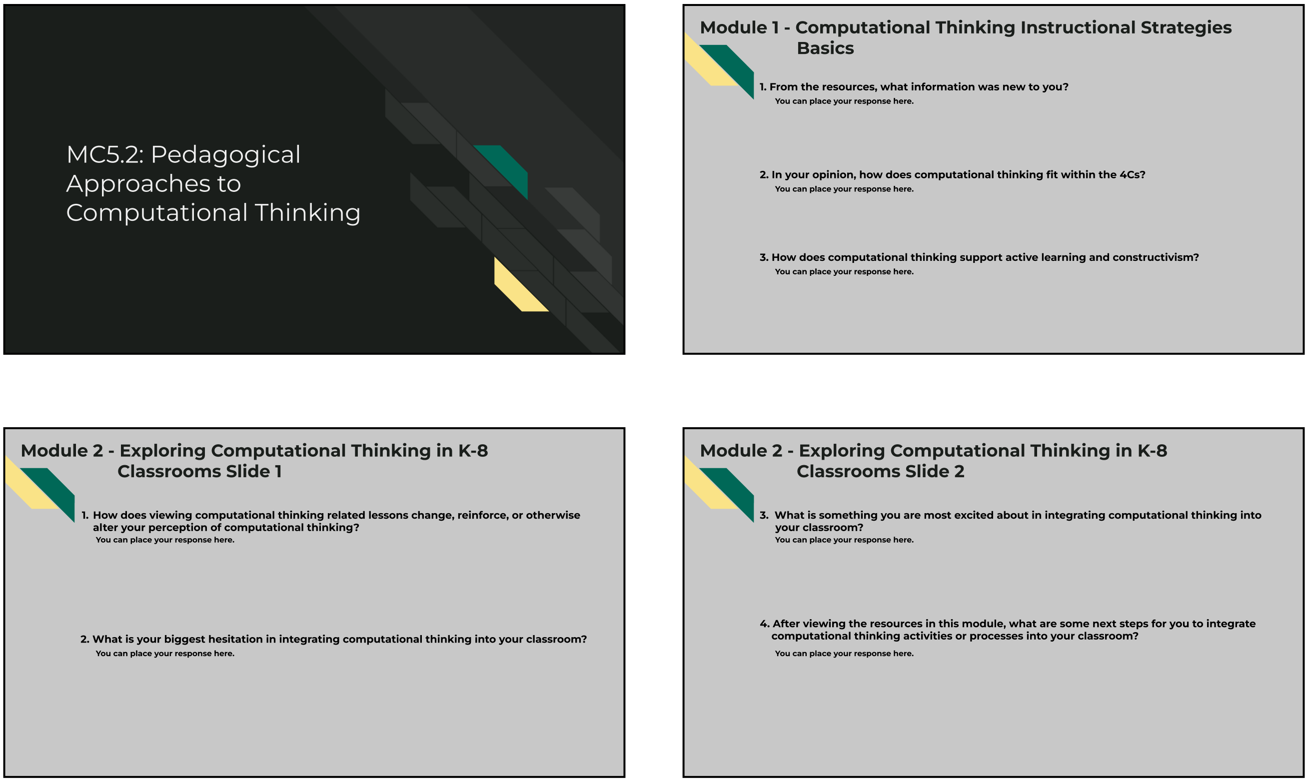


Fig. 5 Micro-credential Course 2 reflection journal slides

Table 3). The participants came from undergraduate and graduate pre–service education programs creating a range of prior experience and knowledge. Most of the participants (70%) did not have any teaching experience yet, two of the participants just started a teaching position at the beginning of this study and one participant started teaching while completing their program. The participants who reported having a bachelor's or master's degree as their highest degree just received those degrees in Spring 2020 with 40% of the participants still enrolled in an undergraduate education program. The participants also indicated the grade level and subject area they were interested in teaching. An open–ended question was provided for the selection of 'other' under subject area. The two participants who indicated 'other' stated the specific subject area was "not yet known."

Overarching Research Question

To answer the overarching RQ pre–and post–content surveys, RJs and LPs were analyzed. The RQ was further broken down into CT content and pedagogical content sub questions to better understand the comprehension of both areas.

Overall, the pre–service teachers made gains from the pre– to the post–content surveys, though the difference between the two tests was not statistically significant at the 0.05 alpha level, $t(9) = 1.74$, $p = 0.115$, $d = 0.09$, 95% CI [-0.015, 0.115] (see Table 4). Although the pre– and post–content surveys were not statistically significant, participants reported growth in integrating CT into their classroom in their RJ entries. The teachers' reported their awareness of current practices evolved and their attitudes towards the implementation of CT shifted as stated by a participant, "my thoughts about computational thinking and how I could integrate this approach in my instruction have changed drastically throughout this course."

At the beginning of the micro–credential courses, the pre–service teachers reflected on their hesitation in understanding how they could effectively integrate CT into their class instruction and their misconceptions of what CT is within their RJs. Many of the participants shared their belief that CT consisted only of CS and coding and could not be implemented in all classes. In the absence of understanding, perceptions were misleading as explained by one pre–service teacher, "When I first thought of computational thinking, I thought there was no way that I would be incorporating that into an elementary classroom or have an appropriate opportunity to do so."

During the micro–credential courses, pre–service teachers reflected on gaining a clearer understanding and expressed a positive attitude about CT in their RJs. The pre–services teachers became aware of their current practices and how they were supporting CT. The pre–service teachers also

Table 3 Participant demographics

Demographic	Frequency	Percentage
Teaching Experience		
No Experience	7	70%
Less than 1 year	2	20%
1–5 years	1	10%
Highest Degree		
High School Diploma	4	40%
Bachelor's Degree	4	40%
Master's Degree	2	20%
Interested Grade Level		
PreK—2nd	4	40%
3rd—5th	3	30%
6th—8th	3	30%
Interested Subject Area		
All Subjects	3	30%
Math	1	10%
Science	3	30%
Other	2	20%
Race/Ethnicity		
White	9	90%
Asian	1	10%

recognized that applications of CT were currently being integrated in their classroom instructional delivery but explicit connections to CT and use of CT vocabulary were not evident in their lessons and curriculum. This realization created a sense of awareness and formality as conveyed by one participant, "what I do in the classroom is computational thinking [and] can actually be integrated into all subjects' areas."

As the micro–credential course concluded and the pre–service teachers' knowledge broadened, their responses tremendously changed. Their awareness of current practices evolved and attitudes towards the implementation of CT shifted as stated by one participant "before, I would have thought computational thinking was only related to computer science and coding and never would have known how this could be beneficial in my classroom." Although the pre– and post–content surveys were not statistically significant, the pre–service teachers better understood that CT can be integrated in K–8 classrooms across content areas and they had been demonstrating the application of CT unknowingly. This growth prompted a deeper dive into the specific content the pre–service teachers already knew and acquired within the micro–credentials, specifically through a CT and pedagogical content lens.

Computational Thinking Knowledge Performance (RQ1)

Through the RJs, the pre–service teachers indicated growth in their knowledge and integration of CT during the micro–credential, but a deeper dive into the specific CT content and integration practices previously known and acquired within the micro–credential was conducted through RQ1.

The pre–post content survey was broken down into CT and pedagogical concepts. Of the 30 questions on the pre– and post–content surveys, 11 questions focused on CT content. The scores for the pre– and post–CT content surveys were not statistically significant at the 0.05 alpha level, $t(9) = -0.27$, $p = 0.795$, $d = 0.14$, 95% CI [-0.115, 0.091], with the post–CT content scores a hundredth of a point lower than the pre–CT content scores (see Table 5). Within the CT content, 60% of the participants' scores either remained the same or increased from the pre– to post–test with 40% of the participants' scores decreasing. This downward trend was further reviewed to better understand if specific questions were consistently missed in both the pre– and post–surveys. Three questions were answered incorrectly by most of the participants in both the pre– and post–CT content surveys. These three questions focused on the core practices of CT. Overall, the participants misidentified three of the four core practices: developing and using abstractions, creating computational artifacts and testing and refining computational artifacts.

Although the post–test scores were lower than the pre–test scores, the participants reflected growth in their CT knowledge through the RJs and integration of CT in their classrooms through lesson planning. In the RJs, three main themes emerged in changes in pre–service teachers' knowledge of CT: (1) teaching practice, (2) problem solving skills and (3) use of CT language. In addition to the previously identified misconceptions of CT (see Overarching Research Question section), the participants included reflections of apprehension of the application of CT in the classroom and everyday life. One participant stated,

Table 4 Pre- and post-content survey paired *t*-tests

Test questions	*M*	*SD*	*SEM*	*t*(9)	*p*	95% CI for the difference *LL*	95% CI for the difference *UL*	*d*
Pre-test All	0.80	0.79	0.03	32.21	0.000	0.744	0.856	
Post-test All	0.85	0.05	0.02	53.44	0.000	0.814	0.886	
Post-test – Pre-test All	0.05	0.09	0.03	1.74	0.115	-0.015	0.115	0.09

Table 5 Pre- and post-CT content survey paired *t*-tests

Test questions	*M*	*SD*	*SEM*	*t*(9)	*p*	95% CI for the difference		*d*
						LL	*UL*	
CT Pre-test	0.71	0.11	0.04	20.35	0.000	0.633	0.791	
CT Post-test	0.70	0.10	0.03	23.02	0.000	0.631	0.769	
CT Post-test – CT Pre-test	-0.01	0.14	0.05	-0.27	0.795	-0.115	0.091	0.14

"I do not know much beyond the definition such as how we would do this with technology, without technology, incorporate it into the classroom, etc." Another participant said, "I have very few ideas on what it actually looks like when a person is thinking computationally."

As the pre–service teachers moved through the CT content, they began identifying when they use CT practices in their everyday and educational lives such as in their internships and classroom observations. Elements of decomposition and abstraction emerged in their RJ entries as expressed by one participant,

> I have observed many different learners in different classrooms. In one classroom that I observed and taught in last year, I noticed that the students tended to be less engaged when they were seated in groups larger than four. In these instances, the students would fight and distract each other, and would not be as engaged in the science experiments we were doing. After noticing this, my peer and I who were running the lesson decided to create more groups for our experiments so that the students could remain more focused and retain more from the lesson. Using the patterns we observed, we were able to better engage students.

Throughout this growth, even amidst the apprehension of "what it actually looks like," participants were able to identify when CT practices were used in their teaching and how they were unaware of these practices due to lack of CT vocabulary knowledge, as articulated by one participant's RJ entry,

> I have definitely gained more of an understanding regarding computational thinking in the past couple of modules – not only regarding what computational thinking is in itself, but also the ways in which I have already used computational thinking in my classroom, as well as the logic behind the thinking such as decomposition, pattern recognition, abstraction and algorithmic thinking.

This growth of CT knowledge and integration into teaching practices was further displayed in the participants' LPs, which were analyzed through the lens of the four core practices of CT (see Fig. 1; K12 CS, n.d.). Within the participants' LPs, each of the four core practices of CT were present, with the practice developing and using abstractions yielding the most occurrences and recognizing and defining computational problems yielding the least occurrences (see Table 6).

Within these LPs, 50% ($n=5$) of the participants did not have evidence of all four CT core practices. Four participants did not have any evidence of recognizing and defining computational problems and one participant did not have any evidence of testing and refining computational artifacts. Two participants who had evidence of all four core practices stood out among the group in opposite ways. One participant had the best CT integration within the LP as evidenced through the reflective questions provided to students and teacher–directed support. The other participant utilized CT vocabulary within their LP but had the students using CT at a very basic level, especially in the first core practice, recognizing and defining computational problems. In their LP, there was very little connection to real–world problems and solutions and although the participant included, "collaborating with others to solve problems logically and efficiently" there was no problem explicitly stated in the LP.

Pedagogical Knowledge Performance (RQ2)

Beyond CT growth, pedagogical content knowledge was also further reviewed through RQ2. For pedagogical concepts, the participants did show content knowledge gains in the pre– and post–pedagogical content survey, which was also reflected within their reflections through the connections of pedagogical practices with the CT content and was further evidenced through their statements of the most impactful content from the micro–credentials.

Of the 30 questions on the pre– and post–content surveys, 19 questions focused on pedagogical concepts. The scores for the pre– and post–pedagogical content surveys were statistically significant at the 0.05 alpha level, $t(9)=2.27$, $p=0.049$, $d=0.12$, 95% CI [0.000, 0.172], with the post–pedagogical content scores being almost one–tenth of a point higher than the pre–test scores (see Table 7). Within the pedagogical content, 90% of the participants' scores either remained the same or increased from the pre– to post–test with one participant's score decreasing. The pedagogical questions were reviewed to better understand if specific questions were consistently missed

Table 6 Core practices of CT evidence in pre-service lesson plans

Core practices of CT	Frequencies ($N = 230$)	Example codes
Recognizing and defining computational problems	26	"break down the process into small steps" "Each group will work together to break down the stages of hurricane formation into easily understandable chunks." "How can I successfully create the maze without the marble rolling off? What steps am I going to take to create my maze? How should I begin this project?"
Developing and using abstractions	89	"Students will recognize that patterns of association can also be seen in bivariate categorical data by displaying frequencies and relative frequencies in a two-way table." "Understanding the algorithmic process that occur in a cell and generalize those to everyday life." "Students will be able to differentiate the relationship between electricity and magnetism and how this relationship affects our world."
Creating computational artifacts	70	"How to use their creativity skills to create a model." "Students will work to design a 'functional factory' based on how the cell runs." "Students will collect data on how strong their electromagnet is and visually represent that data in a graph."
Testing and refining computational artifacts	45	"Students will individually complete an exit ticket about how they solved a problem. They will also discuss how they overcome obstacles and problems they faced to find a solution to their answer." "Students will be able to examine their classmates' mazes and evaluate them. Students may need to reconstruct parts of their maze if it does not work during their tests with the marble." "How did you determine your hypothesis was supported/unsupported? What would you change about this experiment if you had to do it again?"

in both pre– and post–surveys. Three questions emerged from this review, two which focused on formative assessments and one which focused on constructivism.

The participant reflections supported the pre– and post–pedagogical content survey differences with the pre–service teachers making connections between their emerging teaching practices and CT. In their reflections, the pre–service teachers further connected CT to pedagogical practices traversing various subjects. For example, one of the pre–service teachers said,

> By viewing computational thinking related lessons, I gain a deeper understanding of truly what it means to incorporate computational thinking inside the classroom beyond a computer science course. It reinforces the idea I have been forming of what it would look like in a math, ELA, or science class.

Another pre–service teacher also reflected on their emerging teaching practices, connecting CT into their future classes,

> I am very excited to try to incorporate computational thinking into my ELA instruction. I am in a 5th grade classroom of advanced students. The 5th grade curriculum involves lots of reading and writing which students are not always thrilled about. I'd like to incorporate computational thinking and create writing assignments and options that engage the students with tasks and prompts that evoke problem solving and thinking.

Table 7 Pre- and post-pedagogical content survey paired *t*-tests

Test questions	*M*	*SD*	*SEM*	*t*(9)	*p*	95% CI for the difference *LL*	*UL*	*d*
Pedagogical Pre-test	0.85	0.14	0.04	19.70	0.000	0.752	0.948	
Pedagogical Post-test	0.94	0.06	0.02	52.65	0.000	0.896	0.976	
Pedagogical Post-test – Pedagogical Pre-test	0.09	0.12	0.04	2.27	0.049	0.000	0.172	0.12

From this pedagogical analysis, three themes emerged further supporting the change in knowledge showcased in the pre– and post–content surveys: 1) modeling CT in different domains, 2) embedding CT into solving problems and knowledge representation and 3) connecting CT into other pedagogical frameworks such as higher levels of Bloom taxonomy, the 4C's and twenty-first century skills.

Modeling CT in Different Domains The first theme, modeling CT in different domains, includes the realization of how CT can be used in various content areas to support learning and solve problems authentic to learners. Two participants exemplified this theme in stating, "computational thinking can be evident in almost every lesson. It is already used inside the classroom within numerous different activities that an educator may not even be aware of" and

> I have noticed that computational thinking is a problem–solving approach that we use in our everyday life. I am excited to integrate some of these lessons to my future classroom as these activities can help students understand more about complex issues, topics, and concepts, and topics. Collaborating, communicating, and working with other peers will help each student grow as learners.

Embedding CT into Solving Problems and Knowledge Representation The second theme, embedding CT into solving problems and knowledge representation, included participants directly connecting CT to critical thinking, especially in the decomposition and abstraction CT concepts. For example, the concept of decomposition was mentioned to include CT in their lessons as stated by two participants, "Breaking ideas down in order to understand the bigger picture or decomposition, is closely related to critical thinking, which involves interpreting, analyzing, and evaluating data" and "critical thinking is required to decompose the problem and begin the process of solving it. Oftentimes in difficult situations, a bit of creativity can be a good way to find a solution."

Connecting CT into Other Pedagogical Frameworks Although the first two themes included concepts from the 4Cs such as collaboration, communication and critical thinking (Common Sense Education, 2016), the third theme, connecting CT into other pedagogical frameworks such as higher levels of Bloom taxonomy, the 4C's and twenty-first century skills, included direct connections of CT to pedagogical frameworks, demonstrating pre–service teachers' understanding of the application of CT into their teaching practices. Two participants summed up this third theme stating,

Table 8 Pre-service Teachers' Stated Impactful Content

Content	Participants ($N=8$)	Occurrences ($N=12$)
Pedagogy	6	
4Cs		2
Active Learning		3
Perseverance		2
social emotional aspects		1
Computational Thinking	2	
Unplugged Activities		2
Digital Coding		2

> When thinking about computational thinking, we have been associating it with higher level thinking and problem solving. The 4Cs could be said to make up how students can use computational thinking. There can often be collaboration and communication as students strive to solve problems or create solutions, leading to critical thinking or high–level thinking.
>
> and
>
> Using these skills in computational thinking will help students to have confidence and persistence when dealing with complexity. Most importantly, as Common–Sense Education (2016) mentioned, when technology is used strategically, it can enhance the 4C's in the classroom to promote high–order thinking skills. These higher order thinking skills will help students thrive in their work and life.

The pre–service teachers were also asked what content was the most impactful throughout the micro–credentials. This question was included in the RJ entry 16 and focused on the main CT in course one and the pedagogical concepts in course two such as the 4Cs, active learning, perseverance and social emotional aspects (persistence and resilience). Although there were only eight responses collected for this RJ entry, 75% ($n=6$) of the participants indicated pedagogical content was the most impactful with active learning content receiving the most mentions and 25% ($n=2$) of the participants indicated computational thinking content was the most impactful (see Table 8).

Discussion

Through this micro–credential, participants reported more awareness and understanding of CT for both their everyday life and teaching practices. Pre–service teachers' exposure and gained knowledge through the micro–credential demonstrated that they were integrating CT in the classroom but were unaware of this integration prior to the micro–credential. For CT concepts, the participants did not show content knowledge gains in the pre– and post–CT content survey but did reflect on their new awareness of CT elements within their current content and emerging teaching practices and their knowledge growth of CT language. This was also evidenced in the integration of the four core practices of CT (K–12 CS Framework, 2016) in their original LPs. Through their reflections, the pre–service teachers discovered how they are currently applying CT in their everyday lives, how CT connects to the pedagogies they are learning in their education courses and how CT could manifest in their classrooms.

The connection of CT to their previous teaching experiences led to more problem–solving approaches where the pre–service teachers began connecting their use of CT within observations of classroom practices to the students' use of CT in their classroom, specifically through open–ended problems, communication and collaboration. One participant made this connection directly stating in their RJ entry,

> To use problem solving skills in order to figure out solutions. It is very beneficial for kids to work on building solutions themselves rather than always being told what to do, as this develops creativity, critical thinking, and practical problem–solving skills that can be used in all aspects of life.

The participants' selection of pedagogical content as the most impactful within the CT micro–credentials further support the increase in the post–pedagogical content survey scores, as the participants may have preferred and better understood that content due to their higher prior knowledge, as evidenced in the mean pre–pedagogical content score of 0.85 (0.14; see Table 7) as compared to the mean pre–CT content score of 0.71 (0.11; see Table 5). Although the pedagogical pre– and post–content survey scores significantly increased and the participant's reflections indicated growth in pedagogical concepts and the participants identified pedagogy concepts as the most impactful in the micro–credentials, a disconnect emerged between the use of technology tools and unplugged activities to support CT and the difficulty of implementing CT into the participants' future classrooms. Since many of the participants did not yet have their own classroom, they may have been more uncertain in which was best, technology tools or unplugged activities, for their classroom as explained by one of the participants, "I feel that an unplugged activity would be best since I am not sure what type of technology access my future classroom will have." Other participants expressed the difficulty of potentially using CT in their classes, especially as they utilize more student–centered practices as expressed by one participant,

> I think the hardest part about integrating computational thinking is that it requires students to create and design, so they are doing most of their work on their own and through their own ideas. For some students, having too much creative space and "wiggle room" can be distracting and for others, not having as much of a direction towards things can be difficult.

The downward trend found in the pre– and post–CT content survey on the core practices of CT with the misidentification of three of the four core practices should be further reviewed in both the measurement of the identification of these core practices and in the instruction participants receive regarding these practices. Although there were gains from the pre– to post–pedagogical content survey, a review of the pedagogical questions was completed to better understand if any questions were consistently missed in both pre– and post–surveys. The three questions that emerged focused on formative assessments and constructivism. This lack of content was also seen in the RJs and LPs. Although the pre–service teachers connected formative assessments and constructivism within their reflections, their knowledge of these elements as indicated in their post–content survey scores and the limitations of these concepts in their LPs indicates further support is needed for pre–service teachers.

Limitations

Within this study, various limitations were present. The study included 10 consenting participants but only eight of the 10 participants' RJs were accessible by the lead researcher. Google Drive was utilized for the RJs with a sharable link provided in course one. One participant's RJ was in their trash at the time it was accessed for data analysis, thus it was not retrieved. Another participant had restricted the access to the RJ at the point of retrieval for data analysis and the lead researcher was not included in the access.

In convergent mixed methods research, unequal or equal groups can be used to collect the quantitative and qualitative data (Creswell & Clark, 2018). Creswell (2014) suggests participants used in convergent mixed methods research be from the same group, as the merging of the quantitative and qualitative data is better the more similar the participants. Creswell and Clark (2018) note that using the same participants in equal groups may lead to smaller sample sizes for data collection and can lead to low statistical power in the quantitative analysis. Due to the small number of participants in the study, the quantitative analysis may have low statistical power, the "test's sensitivity in detecting significant results" (Sprinthall, 2012, p. 457). In addition to the possible low statistical power, although the pre– and post–content surveys were reviewed by content experts prior to use, they were not tested prior to implementation with these pre–service teachers. Further review of the questions is needed, especially with the questions that most participants did not answer correctly to ensure they are valid.

Conclusion

In the ever–growing expected knowledge of pre–service teachers (Falkner et al., 2018), designing platforms and ecosystems that promote and sustain innovative CS teacher education is needed. The addition of micro–credentials focused on CT is one solution that can be used to grow pre–service teachers CT and pedagogical knowledge but should not be the only pathway for pre–service teachers to learn about CT. As shown in this study, the use of reflective practices and lesson planning can guide pre–service teachers in their CT knowledge growth, but continued follow–up, modeling of classroom implementation and further support in the difference between the four core practices of CT, formative assessments and constructivism and how these fit within the classroom and lesson planning is needed.

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Declarations

Ethics Approval The instruments and methodology for this study was approved by the Institutional Review Board committee of Loyola University Maryland (HS-2021–001).

Consent to Participate Informed consent was obtained from all individual participants included in the study.

Conflicts of Interests The first author is an unpaid Strategic Planning Advisor for the Maryland Elementary School Computer Science Coaches Program and an unpaid member of the Teacher Incentives Workgroup within this program. The other authors have no conflicts of interests.

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