

Bridging Computational Thinking Knowledge and Classroom Practice: A Mixed-Methods Study of Preservice Mathematics Teachers in Ghana

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Abstract

Preservice mathematics teachers are increasingly required to incorporate computational thinking (CT) into school mathematics, but evidence about whether CT knowledge actually transfers into classroom practice remains limited, especially within African settings. This research investigated how preservice mathematics teachers' CT knowledge related to their observed CT enactment during school-based teaching, and explored the contextual and pedagogical factors that influenced that enactment. A convergent parallel mixed-methods approach was used with 42 third-year Bachelor of Education (Mathematics) students at the University for Development Studies, Ghana. Participants completed a CT knowledge assessment based on Weintrop et al.'s (2016) four-practice taxonomy and were observed teaching two mathematics lessons; in addition, 16 participants took part in interviews and lesson-plan analysis. CT knowledge was moderate ($M = 61.4\%$, $SD = 12.8$), while CT enactment was low ($M = 1.42/3$, $SD = 0.58$). CT knowledge showed a positive association with enactment, $r(40) = .34$, $p = .028$, accounting for roughly 12% of the variance. The qualitative results pointed to curriculum pacing pressure, limited mentor modelling, an examination-oriented culture, and confidence gaps as constraints. These findings underscore the need for teacher education to reinforce pedagogical translation, mentor modelling, and context-responsive CT enactment.

Keywords: Computational Thinking; Preservice Mathematics Teachers; Knowledge-Practice Gap; School-Based Teaching; Convergent Parallel Mixed Methods; Ghana

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INTRODUCTION

Computational thinking (CT) has become a crucial element of mathematics teacher education as preservice teachers are required not only to understand computational modes of reasoning, but also to incorporate them effectively into mathematics teaching. The recent research highlights that CT is gaining increasing attention in teacher preparation, specifically in the field of STEM education, although there is a diversity of approaches to fostering teachers' CT knowledge and pedagogy (Listiaji & Molnár, 2025). Moreover, there is evidence that teachers struggle to apply their CT knowledge in a pedagogically appropriate way in their classrooms despite an awareness of its importance (Dong et al., 2024; Zahid, 2025).

This distinction between knowing CT and enacting CT is of particular importance for preservice mathematics teachers, because knowledge of computational practices does not always guarantee the effective use of them in school-based teaching. Recent studies of preservice teachers therefore stress the importance of investigating the ways in which CT is manifested in authentic teaching activities, rather than considering CT knowledge and classroom enactment as equivalent (Dektor et al., 2024; Mahlaba, 2025). In the field of mathematics education, Weintrop et al. (2016) developed an especially useful framework for examining CT by defining four practice categories: data practices, modelling and simulation practices, computational problem-solving practices, and systems thinking practices. This taxonomy provides a discipline-specific basis for conceptualizing CT in mathematics and for investigating the knowledge that preservice mathematics teachers have about CT and how the practices are manifested in their classroom instruction. Accordingly, the present study adopts Weintrop et al.'s (2016) four-practice taxonomy for conceptualizing CT knowledge and observed CT enactment and for investigating the extent to which preservice mathematics teachers' knowledge of the CT practices is reflected in their classroom practice during school-based teaching.

This gap between building CT knowledge and observing CT practice is an active policy problem in contexts, such as Ghana, that have recently integrated CT into national curricula and into preservice teacher preparation with the explicit expectation that enhanced CT knowledge will lead to enhanced CT teaching (National Council for Curriculum and Assessment [NaCCA], 2023). This assumption has received limited empirical investigation. The most relevant Ghanaian study to date, Gyamfi et al. (2025), found that preservice teacher trainees were able to demonstrate an understanding of the theoretical underpinnings of Ghana's computing curriculum while also exhibiting substantial deficiencies in practical implementation readiness, although this conclusion was based on self-reported preparedness rather than observed teaching and focused on computing education in general rather than CT enacted in mathematics lessons in particular. Whether a comparable gap exists between what preservice mathematics teachers know about CT and what they are observed to do with it in a mathematics classroom, and if so why, has not been directly investigated.

The study addressed that issue by investigating not only whether preservice mathematics teachers' CT knowledge predicts their CT enactment but also what stands between the two when it does not. Addressing both required a research design capable of estimating the strength of the relationship between the two while investigating the nature of that relationship. A convergent parallel mixed-methods design (Creswell & Plano Clark, 2018) was therefore used: quantitative and qualitative evidence about the same lessons and the same participants were gathered concurrently, analyzed separately, then combined, with the qualitative findings intended to explain rather than supplement the quantitative.

The purpose of this study was to investigate the relationship between preservice mathematics teachers' computational thinking (CT) knowledge and their enacted CT in school teaching and explore the contextual and pedagogical factors shaping the translation of CT knowledge into classroom practice. The purpose was addressed through the following research questions:

RQ1. What is the relationship between preservice mathematics teachers' CT knowledge and their observed enactment of CT during school-based teaching?

RQ2. What contextual and pedagogical factors do preservice mathematics teachers identify as shaping the enactment of CT during school-based teaching?

Coupling a validated CT knowledge assessment with CT enactment observations in classrooms and interpreting this relationship through preservice teachers' own accounts: this study contributes classroom-grounded evidence (currently lacking for mathematics teacher preparation in a Sub-Saharan African university context) about the factors that mediate the link between CT knowledge and CT teaching.

LITERATURE REVIEW

Computational Thinking: Contested Definitions and a Persistent Cognitive Framing

Computational thinking has been defined and redefined in ways that critically shape its study. Wing's (2006) original formulation conceptualized CT as an individual cognitive skill, thus, a way of thinking that could be learned by any individual, independently of any particular disciplinary or classroom context. Weintrop et al.'s (2016) characterization narrowed this general definition into a mathematics- and science-specific taxonomy of four practices, providing the field with an accessible observational vocabulary while preserving Wing's underlying assumption that CT is essentially a matter of what an individual knows and can do.

More recently, however, Kafai and Proctor (2022) have argued that this formulation is incomplete: drawing on situated learning theory (Lave & Wenger, 1991), they argue that computational thinking is enacted through participation in a practice community: a classroom, a mentorship relationship, an institutional culture and not simply expressed from an individual's stored knowledge. This theoretical shift has significant methodological implications that the preservice-teacher CT literature reviewed below has largely overlooked: if CT is substantially situated rather than purely cognitive, then studies that measure only preservice teachers' CT knowledge or confidence, without observing the classroom conditions in which they attempt to enact it, are measuring only part of what determines whether CT teaching actually happens.

Building Preservice Teachers' CT Knowledge: A Field that Measures Knowledge More Often than it Observes Practice

A substantial body of research has been done exploring the ways in which mathematics teacher-education programs can reinforce preservice teachers' CT knowledge and confidence, but this research has skewed toward using knowledge assessments, confidence surveys, or brief microteaching exercises rather than observing CT enactment in authentic, ongoing classroom teaching. Barlow et al. (2023) found that preservice K–8 mathematics teachers had initially fragmented CT concepts centered on computer science that became more mathematically specific with deliberate CT-integrated tasks but did not examine whether these shifts persisted in subsequent classroom teaching. Similarly, Moon et al. (2023) report a CT intuition shift in preservice teachers after a dedicated methods course, using course-based tasks rather than

field-based teaching as a measure. Finally, in an experimental design, Tadeu et al. (2025) found that a design-based learning intervention achieved significantly better CT scores, with preservice elementary mathematics teachers, particularly in algorithmic thinking and problem-posing; a promising result in showcasing how CT knowledge might be achieved, but one that, like the above studies, ends its analysis at the point of knowledge acquisition rather than examining classroom enactment outcomes. At the level of the field as a whole, Yun and Crippen's (2025) systematic review of CT integration in preservice science-teacher education arrived at a similar conclusion, noting explicitly that very few of the reviewed studies examined whether preservice teachers' CT preparation translated into observed classroom practice.

The most notable exception is also the most similar methodologically to the present study. Tankiz and Atman Uslu (2023) used a convergent mixed-methods design to explore preservice teachers' CT skills and their perceived readiness to teach CT, finding that self-reported CT skills did not necessarily match up with self-reported CT teaching readiness. An important early indication of the knowledge–practice divergence explored herein, this is nonetheless a divergence between two self-reported outcomes rather than between knowledge and directly observed practice, and it is unclear whether the same outcome would be observed, to the same extent, if actual enacted teaching rather than teaching readiness was the dependent variable.

Evidence from Observed Classroom Integration, and its Limits for the Present Question

A smaller body of work has examined CT-mathematics integration more directly by observing such integration in the classrooms, this offers a useful but narrower precedent. Israel and Lash's (2020) two-year qualitative study of elementary teachers integrating computer science and CT into their mathematics instruction identified three levels of integration in the observed classroom practice: no integration (CT and mathematics were taught separately), partial integration (CT reinforced a mathematics concept or vice versa), and full integration (CT and mathematics were taught as a single, mutually constitutive activity). Notably, they found full integration to be the least common of the three, with teachers reporting the increased cognitive load of simultaneously teaching CT and mathematics as a specific impediment. This finding illustrates that even motivated, supported in-service teachers in a well-resourced setting found the most challenging type of CT-mathematics integration to be difficult to pursue. But their study involved in-service elementary-level teachers in the United States rather than preservice secondary-level mathematics teachers in a resource-constrained Sub-Saharan African context, and did not involve any independent measurement of teachers' underlying CT knowledge alongside their observed classroom integration. It is therefore unable to indicate whether the levels of integration observed were limited by teachers' knowledge, by the conditions under which they taught, or by both together which is precisely the question this study was designed to answer.

The Knowledge–Practice Gap in Ghanaian Teacher Preparation

In the Ghanaian context, the research by Gyamfi et al. (2025) was most direct to demonstrate a knowledge–practice gap in computing-related teacher preparation by reporting that preservice teacher trainees demonstrated strong theoretical understanding of the national computing curriculum, but showed substantial gaps in practical implementation readiness in basic schools. While important, these findings are limited in two ways relevant to our current project: they were drawn from perceived levels of preparedness rather than actual classroom observations, and they related to computing education as a general domain rather than CT enactment within mathematics teaching specifically. It is therefore entirely plausible to posit a similar knowledge–practice gap within the more specific domain of CT-integrated

mathematics teaching, but such an assumption has yet to be tested against actual classroom observations. Recent Ghanaian research has also explored preservice mathematics teachers' perceptions of CT as a problem-solving strategy, but this work drew primarily on questionnaire and interview evidence rather than independent observation of CT enactment within school-based teaching (Ofosu et al., 2026).

Synthesis and Research Gap

There are three limitations that emerge across the literature considered together. First, many of the studies focused on enhancing CT capacities of preservice teachers assessed knowledge or confidence gains but did not observe classroom enactment (Barlow et al., 2023; Moon et al., 2023; Tadeu et al., 2025; Tankiz & Atman Uslu, 2023), a limitation difficult to rationalize given the substantially situated rather than purely cognitive nature of CT (Kafai & Proctor, 2022; Lave & Wenger, 1991). Second, whereas CT-mathematics integration has been observed directly in classrooms, the evidence concerned in-service elementary teachers in well-resourced contexts and was not accompanied by an independent knowledge measure (Israel & Lash, 2020), and the relative contribution of knowledge and context to observed practice remains unclear. Third, the most salient evidence of a knowledge-practice gap in an African teacher-preparation context (Gyamfi et al., 2025) has been based on self-report rather than observation and concerned computing education broadly rather than CT enactment in mathematics teaching. Although extant studies have investigated preservice teachers' computational thinking (CT) knowledge, perceptions, and readiness to integrate CT into teaching, understanding of whether and how such knowledge translates into observable classroom practice is limited. Specifically, there is a need for studies that combine a study-developed CT knowledge assessment with evidence of content validity and internal consistency and direct classroom observation of CT enactment as preservice mathematics teachers engage in school-based teaching. Furthermore, little is known about how the relationship between CT knowledge and classroom enactment is moderated by the pedagogical and contextual conditions in which preservice teachers teach. The present study contributes to addressing this gap by investigating the relationship between preservice mathematics teachers' CT knowledge and their observed CT enactment and by using qualitative evidence to elucidate the contextual and pedagogical factors associated with the translation of CT knowledge into classroom practice.

Theoretical Framework

This study is guided by two complementary theoretical perspectives: Shulman's (1986) Pedagogical Content Knowledge (PCK) framework and Lave's and Wenger's (1991) Situated Learning Theory. Together, these perspectives provide a lens for examining the relationship between preservice mathematics teachers' knowledge of computational thinking and their enactment of CT practices in school-based teaching.

Pedagogical Content Knowledge (PCK)

The first is Shulman's (1986) theory of pedagogical content knowledge (PCK), which differentiates between subject-matter knowledge and pedagogically transformed knowledge of the contents to be taught to a given set of learners in a given context. As applied to CT, this distinction predicts that knowing what data practices, modelling, computational problem-solving, and systems thinking are (CT content knowledge) are conceptually separable from knowing how to translate these practices into a manageable, curriculum-compliant exercise in

the classroom (CT pedagogical content knowledge), and that preservice teachers may have the former but not the latter.

Situated Learning Theory

The second perspective is situated learning theory (Lave & Wenger, 1991), which in its application to computational thinking specifically has been extended by Kafai and Proctor's (2022) assertion that CT is enacted via participation in a practice community rather than being expressed from stored individual knowledge. By this account, a preservice teacher's placement classroom, mentor teacher, and institutional assessment culture are not neutral settings against which CT knowledge is applied, but rather active agents in determining whether and in what form CT enactment can occur at all - a perspective that would predict mentor modelling and classroom culture to shape enactment in part irrespective of an individual preservice teacher's knowledge.

Read together, these two perspectives produce a single, testable expectation that underpins this study's design and analysis: CT knowledge (a PCK precursor) should be positively but only moderately associated with CT enactment, because translation from the former to the latter is additionally governed by situated classroom conditions (situated learning theory). The quantitative strand of this study tested the strength of the knowledge-enactment association this framework predicted to be moderate rather than strong; the qualitative strand was designed specifically to elicit the situated conditions and efficacy beliefs this framework identifies as the most likely explanations for whatever gap the quantitative strand revealed. This is the conceptual logic the study's convergent design was constructed to test.

Conceptual Framework

The conceptual framework makes a distinction between CT knowledge, CT pedagogical knowledge, and CT enactment and conceptualizes the relationship among these three as a process of pedagogical translation within a school-based teaching context. The conceptual distinction is justified by the fact that CT knowledge might not be straightforwardly translated into classroom enactment.

CT knowledge refers to preservice mathematics teachers' understanding of data practices, modelling and simulation, computational problem-solving, and systems thinking (Weintrop et al., 2016). CT pedagogical knowledge refers to the ability to transform this knowledge into pedagogically appropriate mathematics instruction, including the selection of appropriate CT practices, the design of curriculum-aligned tasks, anticipation of learners' difficulties, and orchestration of learning activities. This conceptualization echoes Shulman's (1986) notion of pedagogical content knowledge, which differentiates subject-matter knowledge from knowledge of its representations and pedagogy. The conceptualization of CT pedagogical knowledge resonates with findings in CT integration research, where CT integration is seen as a process of connecting CT knowledge with pedagogy and instructional practice (Turgut et al., 2024).

CT enactment refers to observable uses of CT practices during mathematics instruction and, in this study, is operationalized through classroom observations rather than self-reports of intentions or perceptions. In this way, the three constructs are related but different: knowing CT, knowing how to teach CT, and enacting CT. CT knowledge is a resource for pedagogical translation but is not sufficient for enactment, and CT pedagogical knowledge does not ensure enactment because of the influence of context on instructional decisions. Similar findings were

reported in the study with preservice teachers, where CT understanding development and CT integration were found to be related but different processes (Dektor et al., 2024; Moon et al., 2023).

Hence, the framework suggests that CT knowledge, CT pedagogical knowledge, and CT enactment are related through a process of pedagogical translation, which is neither automatic nor linear. The process takes place in specific contexts, which can facilitate or hinder it, including mentor-teacher modelling, curriculum pacing, examination-oriented instructional culture, resources, school culture, and preservice teachers' confidence.

Conceptual Model

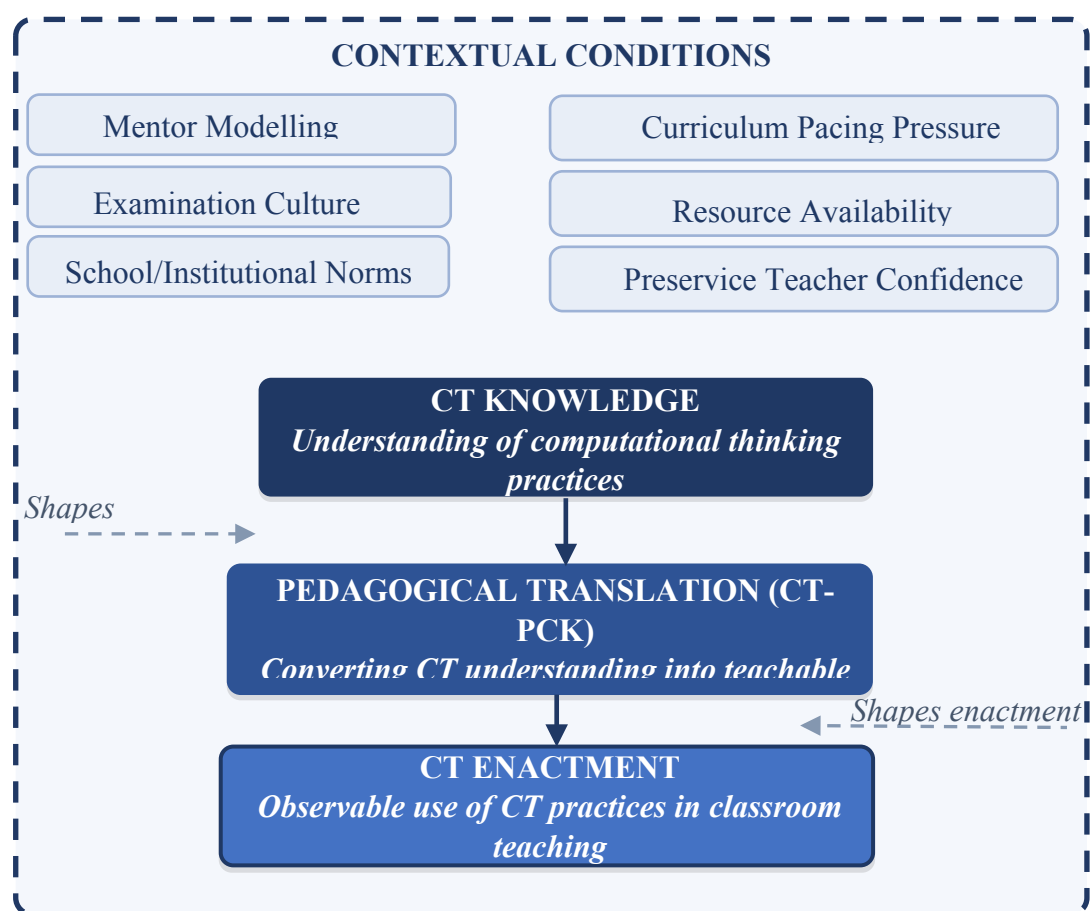


Figure 1: Conceptual Framework Linking Computational Thinking Knowledge, Pedagogical Translation, and Enactment Within Contextual Conditions
Source: Author's conceptualization based on the literature, 2026.

The model therefore assumes that CT knowledge lays the foundation for classroom practice, but that its impact on enactment is mediated through pedagogical translation processes and affected by the social and material conditions of school-based teaching. The framework provides the theoretical basis for exploring both the relationship between CT knowledge and enacted practice and the contextual and pedagogical conditions associated with variation in enactment. However, the present study does not directly measure CT-PCK and therefore does not test the concept of mediation.

METHODOLOGY

Design

The study used a convergent parallel mixed methods design (Creswell & Plano Clark, 2018) in which quantitative and qualitative data addressing the same phenomenon (CT enactment during school-based teaching) were collected concurrently from the same participants, given equal methodological priority, analyzed separately but in accordance with the methodological appropriateness of each strand, and merged at the point of interpretation. The design was dictated by the theoretical framework underpinning the study (Section 2.6), in that estimating the strength of the knowledge-enactment relationship (RQ1) required a quantitative strand while explaining it via the situated conditions and efficacy beliefs identified by the framework (RQ2) required a qualitative strand collected from and interpretable against the same participants and the same observed lessons. Integration took place as a joint display (Section 4.5) merging each participant's quantitative knowledge-enactment profile with the qualitative themes emerging from their interview and lesson-plan data.

Study Context and Participants

The present study was conducted in the University for Development Studies (UDS), Ghana, a public university that offers a Bachelor of Education (Mathematics) program. The participants of the study were 42 third-year Bachelor of Education Mathematics students who undertook school-based teaching in the third trimester of the 2025/2026 academic year. In this study, school-based teaching is part of the B.Ed. (Mathematics) program in which preservice teachers complete teaching activities in partner schools as part of their training. Prior to the school-based teaching component, preservice teachers plan and teach mathematics lessons with support from school-based mentors and/or university supervisors. School-based teaching, therefore, provided an authentic context within which to investigate how preservice teachers enact computational thinking (CT) in mathematics instruction. As such, each participant taught a total of two mathematics lessons ($N = 84$).

All the 42 participants were involved in a CT knowledge assessment and were observed teaching two mathematics lessons for the study. The students had a mean age of 22.6 years ($SD = 1.7$); 64.3% were male and 35.7% were female. For the qualitative strand of the research, 16 participants were purposely selected using a maximum-variation sampling procedure. This sampling strategy was adopted to ensure that a variety of knowledge-enactment patterns that emerged from the quantitative analysis were included in the qualitative study. Specifically, participants were selected to represent a range of CT knowledge performance and enactment levels, from those with relatively high knowledge and high enactment to those with relatively low knowledge and low enactment. Preliminary scoring of the CT knowledge assessments and classroom observation checklists was used to identify participants representing these different performance profiles before the qualitative interviews were conducted. The purpose of this sampling strategy was to allow the qualitative strand to investigate patterns of CT knowledge and enactment in mathematics instruction rather than focusing on the overall quantitative pattern.

Quantitative Strand

CT knowledge was measured using a 32-item CT Knowledge Assessment developed for this study from Weintrop et al.'s (2016) four-practice taxonomy, eight items each from four categories: (data practices; modelling and simulation practices; computational problem-solving

practices; systems thinking practices). Items used a hybrid multiple-choice/short constructed response format that asked participants to identify, apply, or discern CT practices in mathematics-specific contexts; each item was scored 0 or 1 and total score converted to a percentage (0-100%). CT enactment was measured using a CT Enactment Observation Checklist, also organized around the four practice categories, which asked trained observers to rate the extent to which each category was evidenced in an observed lesson on a 0-3 scale (0 = not evidenced; 3 = strongly and purposefully evidenced), with a mean enactment score calculated for the lesson (0-3); participant enactment scores were averaged across their two observed lessons.

Qualitative Strand

Qualitative data were collected from the 16-participant subsample from two sources: semi-structured interviews (conducted individually, within one week of each of their second observed lessons), which explored participants' understandings of CT, their intentions when planning the observed lessons, factors which supported or constrained their attempts to enact CT, and their reflections on any mismatch between their plans and enacted practice; and analysis of lesson-plan documents submitted for each observed lessons, which was used to compare and contrast planned and enacted CT content, providing an independent check on participants' retrospective accounts.

Integration Procedure

In line with convergent parallel design logic (Creswell & Plano Clark, 2018), the two strands were analyzed independently of each other before being merged. Integration was achieved by constructing a joint display (Table 2) which cross-tabulated each of the four quantitative knowledge-enactment profiles (high/high, high/low, low/high, low/low) against the qualitative themes most strongly associated with participants who fall into that profile, thus enabling the study to identify what situated conditions co-occurred with what quantitative patterns, thus explaining, not just reporting, the strength of the knowledge-enactment correlation that was obtained in the quantitative strand.

Validity and Reliability

The CT Knowledge Assessment was reviewed by three mathematics teacher educators for content validity based on Weintrop et al.'s (2016) taxonomy and piloted with 24 preservice teachers who were not otherwise involved in the study, resulting in a Kuder-Richardson 20 (KR-20) reliability coefficient of .82. The CT Enactment Observation Checklist was piloted with video-recorded lessons scored independently by two trained observers, resulting in an intraclass correlation coefficient of .86; all main study observations were conducted by the same two trained observers, blind to participants' knowledge assessment scores, with disagreements resolved through discussion. To enhance coding consistency, the researcher coded the qualitative dataset using predetermined coding categories and constantly compared emergent codes to the original interview and lesson plan data. The coding process involved iterations of reviewing and refining codes to ensure that interpretations were grounded in the dataset. Qualitative trustworthiness was enhanced through triangulation of interview and lesson plan data and member-checking interview summaries with participants. These procedures contributed to the credibility and dependability of the qualitative findings (Lincoln & Guba, 1985).

Data Analysis

The quantitative data were analyzed using descriptive statistics (means, standard deviations) for CT knowledge and CT enactment overall and by practice category, and a Pearson product-moment correlation between participants' CT knowledge and CT enactment scores to answer RQ1. Assumptions of linearity, approximately normal distributions, and lack of influential outliers were explored prior to Pearson correlation.

The qualitative data were analyzed using thematic analysis to address RQ2. The researcher engaged in a systematic process of becoming familiar with the data, initial coding, developing and refining codes, categorizing, and generating themes. Coding was completed manually, without the assistance of qualitative data-analysis software. The initial codes were developed inductively from participants' interview accounts and lesson-plan evidence, and the theoretical framework presented in Section 3 provided a set of sensitizing concepts that informed the interpretation of the data without restricting emergent themes. After the themes were developed and refined, the qualitative findings were integrated with the quantitative results in the joint-display procedure described in Section 4.5.

Ethical Considerations

Formal Institutional Review Board (IRB) approval was not required as the study involved adult participants who could give informed consent. Permission to observe was granted by the University for Development Studies and the head teachers of the schools that hosted the school-based teaching placements. Written informed consent was obtained from all participants, who were advised of their right to withdraw at any point without academic penalty and that data collected as part of the study would not be used in their formal teaching-practice assessment. Data were anonymized using participant codes, stored on password-protected institutional servers accessible only to the research team, and reported only in aggregated or de-identified form.

RESULTS

Quantitative Strand: CT Knowledge and CT Enactment

Table 1: Descriptive Statistics for CT Knowledge and CT Enactment, Overall and by Practice Category (N = 42)

Measure	M	SD	Scale/Max
CT knowledge (overall)	61.4	12.8	0–100%
CT enactment (overall)	1.42	0.58	0–3
Data practices	1.78	0.66	0–3
Modelling and simulation practices	1.35	0.71	0–3
Computational problem-solving practices	1.41	0.69	0–3
Systems thinking practices	1.14	0.73	0–3

Source: Fieldwork, 2026.

Note: CT practice categories were adapted from Weintrop et al. (2016). CT = computational thinking. Enactment scores are averaged across each participant's two observed lessons and,

for practice-category rows, across the four categories of the CT Enactment Observation Checklist.

As Table 1 shows, mean CT knowledge was moderate (61.4%), whereas mean CT enactment was considerably less than the maximum score on the checklist (1.42 of 3). Enactment was most frequent for data practices and least for systems thinking practices. A Pearson correlation between overall CT knowledge and overall CT enactment scores was both statistically significant and of weak-to-moderate magnitude, $r(40) = .34$, $p = .028$. The squared correlation (about 12%) suggests that only about 12% of the variance in observed CT enactment was linearly related to CT knowledge, meaning that most of the variation in enactment was not explained by CT knowledge.

Qualitative Strand: Factors Shaping CT Enactment

Thematic analysis of the interview and lesson-plan data identified five constraining conditions and two enabling conditions describing the circumstances under which participants enacted, or failed to enact, CT in their observed lessons.

Curriculum Pacing Pressure

The most common constraint was the pressure of the curriculum to cover a syllabus within a limited time frame. Participants repeatedly mentioned that CT-integrated activities tended to take more class time than procedural teaching activities and that they couldn't afford the time if the end of term coverage was prioritized even though their lesson plans included such activities. One participant (P03) explained, *"I wanted to give them more time to explore, but I had to finish the topic and time was not always on our side."*

Limited Mentor-Teacher Modelling

Participants with mentor teachers who rarely integrated CT practices felt implicitly pressured to fit in with the norm, especially if the feedback on lesson planning focused on conventional practices of teaching and learning rather than CT-integrated practices. As one participant noted, P07 *"My mentor mostly used the usual method, so I followed what I saw in the classroom."*

Examination-Oriented Instructional Culture

Some participants linked the lack of CT-integrated lessons to a prevailing orientation of mathematics teaching to prepare students for external assessments, citing the perceived prioritization of drilling students on past examination questions as a reason for not including CT-integrated activities. P05 remarked, *"The focus was mainly on past questions because the students had to prepare for the examination, especially the final year students."*

Confidence Gap Despite Conceptual Knowledge

Some participants who scored high on the CT knowledge assessment expressed uncertainty about how to operationalize CT concepts, such as systems thinking, into tangible, class-ready activities. Some participants made a distinction between understanding CT concepts and knowing how to teach CT concepts. As P10 stated, *"I understand what computational thinking means, but I was not always sure how to use it in my mathematics lesson, which was very difficult to integrate in my lesson plan and lesson delivery"*

Resource Constraints

When CT-integrated activities were perceived as requiring the use of technology, simulation tools, or data sets, the lack of such resources in the placement school was cited as a reason for not using the intended activities or modifying them to be less computational and more procedural. P09 explained, *“I had planned to use technology in my lesson delivery, but there were no computers available in my school of practice, so I changed the activity.”*

In addition to these constraints, two enabling conditions were also identified. First, participants who had programming or robotics experience prior to the B.Ed. program found CT-integrated lessons to be a seamless extension of their existing practice. As P02 explained, *“My programming experience made it easier for me to utilize technology and to think through the lesson in steps.”* The second enabling condition was that participants with CT-integrated mentors felt more empowered to attempt CT-integrated tasks even if they ran short on time. P14 noted, *“My mentor encouraged and guided me to try it, so I was not afraid to use the activity.”*

Integration: Joint Display of Quantitative and Qualitative Findings

Table 2 shows each of the four knowledge-enactment profiles discovered in the quantitative strand along with the qualitative themes most linked to the subsample participants belonging to a given profile, integrating both strands in order to address RQ 2.

Table 2: Joint Display Integrating Quantitative Contrasting Knowledge–Enactment Profiles with Qualitative Themes

Profile (Knowledge/Enactment)	n (subsample)	Dominant Qualitative Themes	Illustrative Pattern
High/High	5	Supportive mentor modelling; prior programming exposure	Participants described mentors as actively encouraging CT-integrated tasks and drew on pre-existing computational experience to plan them confidently.
High/Low	6	Curriculum pacing pressure; confidence gap; examination-oriented culture	Participants could describe CT practices accurately but reported abandoning planned CT activities under time pressure or perceived examination demands.
Low/High	2	Resource-light, data-practice-focused tasks; mentor encouragement	Participants with modest CT knowledge nonetheless enacted simple, mentor-modelled data-practice tasks requiring little independent CT planning.
Low/Low	3	Resource constraints; limited mentor modelling;	Participants described multiple, compounding constraints and little

Profile (Knowledge/Enactment)	n (subsample)	Dominant Qualitative Themes	Illustrative Pattern
		examination-oriented culture	exposure to CT-integrated teaching from mentors or curriculum materials.

Source: Fieldwork, 2026

Note: Subsample $n = 16$. Profiles were derived by splitting the subsample's CT knowledge and CT enactment scores. Participants were classified as high or low on CT knowledge and enactment using the respective median scores within the 16-participant qualitative subsample.

The joint display reveals that knowledge–enactment mismatches (the High/Low profile) clustered around participants who described curriculum pacing pressures, an examination-driven culture, and a confidence gap between conceptual knowledge and pedagogical translation, the situated and efficacy-related conditions that the theoretical framework identified as the most probable explanation for a weak knowledge–enactment association. Meanwhile, the few Low/High cases involved simplified, mentor-modeled, resource-light tasks that did not require participants to independently operationalize abstract CT knowledge into novel activities. Together, this integration provides contextual explanations for the observed pattern.

DISCUSSION

Why CT Knowledge Did Not Fully Translate into Enactment

The weak to moderate association found between CT knowledge and CT enactment ($r = .34$) reflects that CT knowledge predicts, but does not fully determine, CT enactment in preservice mathematics teachers' practice. A more accurate interpretation of the findings emerged by distinguishing between CT content knowledge and CT pedagogical knowledge and CT enactment. Those preservice teachers who displayed knowledge of CT practices were not necessarily able to transform them into viable, curriculum-aligned mathematics activities. This is in line with Shulman's (1986) differentiation between subject-matter knowledge and pedagogically transformed knowledge, and recent research findings underscoring the complexity of translating CT knowledge into mathematics-specific pedagogical practice (Turgut et al., 2024). The qualitative findings further suggest that even when preservice teachers displayed the requisite knowledge and ideas to enact CT in mathematics, pacing of the curriculum, mentor modelling, examination-oriented instructional expectations, confidence and resource factors could prevent these from being enacted.

The Role of Mentor Teachers and Situated Context

The most striking pattern from the joint display was the association between mentor-teacher modelling and CT enactment across levels of knowledge: participants with encouraging, CT-experienced mentors enacted CT more frequently whether their own knowledge scores were high or low, whereas participants with mentors who modelled only conventional practice enacted CT infrequently even when their own knowledge was strong. This finding is precisely what situated learning theory (Lave & Wenger, 1991), as extended to CT by Kafai and Proctor (2022), would predict: CT enactment is not merely expressed through an individual's stored knowledge but is co-produced via participation in a practice community whose norms are

substantially shaped by mentor teachers. The finding is also consonant with the overall pattern of low technology-integrated, procedurally focused mathematics teaching documented among practicing Ghanaian teachers by Agyei et al. (2024), suggesting that the instructional culture pre-service teachers encounter during placement may reproduce, rather than offset, existing constraints on technology-integrated mathematics teaching.

Implications for Mathematics Teacher Education and School-Based Teaching

Teacher educators: The findings indicate that CT coursework in isolation might not be sufficient for classroom enactment. Teacher education needs to provide opportunities for preservice teachers to adopt CT ideas into real examples of time-effective mathematics that consider curriculum and classroom constraints.

Mentor teachers and school-based teaching supervision: As mentor modelling has been found to be an important condition for CT enactment, mentors need to be engaged in CT-related professional development and be informed on CT expectations of preservice teachers. Addressing the disconnect between university preparation and school-based mentoring could help bridge the gap between CT knowledge and classroom practices.

Curriculum and policy: It is recommended that universities and curriculum authorities address CT-related curriculum reforms in conjunction with contextual factors associated with classroom enactments such as examination demands, curriculum pacing, and resource provisions. Enhancing CT knowledge alone will have little impact on the persistence of CT classroom practices if the relevant contextual barriers are not addressed.

Limitations

Several limitations qualify these findings. First, the study was conducted at a single university, which limits the generalizability of findings to other institutions with different curricula, mentor-training arrangements, or resources. Second, CT enactment was assessed from two observed lessons per participant; this is sufficient to establish an enactment score, but it cannot reflect enactment across an entire placement or academic year. Third, the qualitative subsample (purposively chosen for maximum variation) included only 16 of the 42 quantitative participants, and the resulting joint display's cell sizes are too small to support strong statements about the representativeness of each profile's themes. Finally, because CT enactment was observed rather than manipulated, the study can identify associations and plausible explanatory mechanisms but cannot make causal claims about what conditions, if changed, would most reliably increase CT enactment.

CONCLUSION

This study investigated the relationship between preservice mathematics teachers' computational thinking (CT) knowledge and its enactment in school-based teaching in Ghana within a convergent parallel mixed-methods design. Results revealed that participants had a moderately developed CT knowledge but comparatively low CT classroom enactment, with only a small positive relationship emerging between the two. Qualitative findings highlighted tensions around curriculum time, mentor modelling, examination-focused pedagogy, confidence, and resources as factors influencing how CT knowledge translated into practice. The findings therefore indicate that CT knowledge, while foundational, is not sufficient for supporting CT classroom enactment. Pedagogical mediation and contextual contingencies thus

need to be considered when developing supports for preservice teachers, as teacher education programs need to include not only CT knowledge but also pedagogical translation of CT knowledge to ensure that beginning teachers can enact CT effectively. Teacher education programs should therefore provide opportunities for practicing pedagogical translation of CT knowledge, enhance mentorship support, and design CT activities for school-based teaching that are responsive to the realities of CT education in Ghana and across Sub-Saharan Africa. Longitudinal studies are needed to understand CT enactment across school-based placements and early-career trajectories, and there is a need to further investigate the potential of mentoring and pedagogical interventions on CT knowledge and enactment in Ghana and beyond.

Declarations

Conflict of Interest: The author declares no conflict of interest

AI use Declaration: The author declares the use of Claude 3.5 Sonnet assist in the creation of figure 1. The author has examined and verified the accuracy, appropriateness, and originality of the figure and is solely responsible for its content.

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