Integrating Computational Thinking across Elementary Subjects

Purpose and Research Questions

Computational thinking (CT) is a skillset that enable individuals, not just computer scientists, to identify and solve problems logically and systematically (Wing, 2006). Researchers and educators believe that CT should be introduced at an early age to cultivate problem-solving skills across disciplines (Denning, 2017; Weintrop et al., 2015; Wing, 2011). Individual studies have found that incorporating CT education into other subject teaching (integrated CT education, in short) improved students' problem-solving skills, motivated their learning, and provided cohesive and interdisciplinary learning experiences to help them understand the technologically advanced world around them (Becker & Park, 2011; Liao et al., 2024; Lv et al., 2022; Tsukamoto et al., 2016; Wang et al., 2021; Yeni et al., 2023). However, those studies vary widely in the instruction design, student populations, and topics or subject areas. This variability makes it difficult to identify which specific design features contribute to effective integrated CT education. As a result, there has been a lack of documentation on preservice teacher (PST) preparation for integrated CT education (Alejandro et al., 2024; Dong et al., 2023; Yun & Crippen, 2024).

This study aims to address this gap and examine PSTs' teaching of integrated CT lessons across elementary subjects. We used the framework of immediate contextualized technological pedagogical content knowledge (iXTPACK) (Brianza et al., 2022; Mishra, 2019; Rosenberg & Koehler, 2015). It refers to the knowledge of tailoring technology, pedagogy, and content to the specific interests and needs of students, thus making lessons relevant and engaging. Our research questions are: 1) What iXTPACK components in integrated CT lessons predicted the changes of students' CT knowledge? 2) What iXTPACK components in integrated CT lessons predicted the changes of students' subject knowledge?

Theoretical Framework

The iXTPACK framework is rooted in the technological pedagogical content knowledge (TPACK) framework (Mishra & Koehler, 2006). TPACK refers to three types of knowledge, namely technology, pedagogy, and content knowledge, and their intersections that teachers need to successfully teach technology-assisted classrooms. iXTPACK is an extension of TPACK by adding the immediate context (iX in the acronym) knowledge. According to Brianza, et al. (2022), iX refers the environment surrounding learners at the time of learning, such as specific events or personal experiences. Studies have shown the benefit of iXTPACK classroom application on students' learning outcome and interests (Tanjung, 2022; Wardoyo & Sunismi, 2024),

Positive outcomes have been reported in studies of integrated CT education with the use of age-appropriate technology and active learning strategies (Liao et al., 2024; Lv et al., 2022; Wang et al., 2021; Yeni et al., 2023). While they explored different types of integration from the perspectives of content focus (Israel & Lash, 2019) , TPACK (Zha et al., 2022), content order (Hurley, 2001), and content dependency (Zhou et al., 2024), little is known about how to effectively interweave CT concepts with subject content, and how technology, pedagogy, and contextual factors interact to influence this integration.

This knowledge gap is particularly concerning in the context of teacher education, as it suggests that PSTs may not be adequately prepared to implement integrated CT education in their future classrooms. As a result, existing studies have shown that teacher preparation for integrated CT education is still in its formative stage, with a significant amount of research focusing on PSTs' CT or technological CT knowledge development (Alejandro et al., 2024; Dong et al., 2023; Yun & Crippen, 2024).

Methods

A mixed-method approach called concurrent triangulation design was utilized in this study (Creswell & Clark, 2010). We collected both quantitative (pre/post-assessments) and qualitative (video) data simultaneously and independently. Next, patterns were extracted from qualitative analysis of videos and converted into numerical values for the quantitative analysis.

Participants

Sixty-six PSTs from four cohorts majoring in elementary education at a southern university in the U.S. participated in this study. They included 64 females and 2 males. Their average age was 24.

Four hundred and eighty-five elementary students who were taught by those PSTs and provided their assent and submitted parental consent forms participated in this study. They came from 66 classes at 33 local schools, among which 88% were Title I schools. Classes and students were already pre-determined as a part of PSTs' teaching practicum. The subject areas were decided based on PSTs' interests.

Procedure

Prior to their classroom teaching, PSTs received a nine-day training over two semesters (Table 1). The training started with CT and robot workshops consisting of direct instructions, small group hands-on practices, and reflective discussions. Next, PSTs participated in sample lessons in each subject at lower and upper elementary levels respectively. Each lesson followed Hurley's (2001) sequential model and demonstrated harmonious interplay between the iXTPACK components. At the end of each day, they worked in small groups and generated lesson ideas. At the end of each semester, PSTs worked in small groups and developed lesson plans under the facilitation of faculty.

-insert Table 1 about here-

PSTs taught their integrated CT lessons in the third and last semester of their teaching practicum. Prior to that, a team of faculty experienced in subject content and CT teaching worked with PSTs to facilitate their lesson planning and co-develop the pre/post-assessments. PSTs were instructed to teach one integrated CT lesson and follow Hurley's (2001) sequence of teaching (Figure 1). In the CT direction instructions, they needed to teach and demonstrate the use of robots and coding or unplugged activities with robots. In the integrated CT practices, PSTs were instructed to use small group activities and on-going facilitations to help students solve CT and subject problems.

-insert Figure 1 about here-

Data Sources

PSTs recorded their lessons and submitted them to the course management system. They also submitted after-lesson reflections summarizing their experiences of teaching integrated CT lessons. Students in the PSTs' classes took the pre-assessments before and the post-assessments after the lessons. The pre/post-assessments for each lesson had the same set of questions, including three-to-four objective questions measuring students' knowledge of subject content and CT respectively. The subject content questions varied across different classes. Although the CT questions also varied across the lessons, they all focused on elementary students' use of algorithmic thinking and pattern recognition skills in the block coding or unplugged activities.

Analysis

Four independent variables, representing specific iXTPACK components, were generated from the analysis of the videos. They were *context*, *technology*, *CT student practice*, and *content dependency* as detailed in Table 2.

-Insert Table 2 here.-

Two variables, including *CT impact* and *subject impact*, were created from students' responses to the pre/post-assessments. Effect sizes were calculated using Hedge's *g* (Rosnow, 2003) for students' CT and subject knowledge change separately. To facilitate the comparison across lessons, these effect sizes were transformed into binary variables called *CT impact* and *subject impact*, where the positive values were coded as 1 (indicating positive impact) and negative and zero values were coded as 0 (indicating non-positive impact).

To address Research Question 1, we used a decision tree classification method to predict the *CT impact*. This non-parametric method allowed us to detect the relative importance of the input variables as well as the combination patterns of variables (Breiman, 2017). We utilized the scikit-learn library in Google Colab, implementing the Classification and Regression Trees (CART) algorithm with gini impurity as the splitting criterion (Decision Tree Classifier; Pedregosa et al., 2011). Based on the iXTPACK framework, we examined four input variables: *context* (immediate context), *technology* (technology), *CT student practice* (pedagogy), and *content dependency* (content).

To address Research Question 2, we also used a decision tree classification method to predict the *subject impact* based on three input variables: *context, technology*, and *content dependency*. The same algorithm and tool were utilized in this analysis. We didn't include subject-specific pedagogy because PSTs' facilitation in the integrated CT practices was focused on CT learning with subject support subtly embedded, which obscured the subject-specific facilitation.

Findings

CT Impact

The decision tree fit a maximum depth of 4 and a minimum sample per leaf of 1. The performance of the decision tree classifier was evaluated and compared with the two ensemble modeling algorithms, namely Random Forest (Breiman, 2001) and boosting using the Extreme Gradient Boosting (XGBoost) technique (Chen & Guestrin, 2016). The decision tree classification method using the CART algorithm showed better results than the XGBoost and similar results to the Random Forest, and therefore was chosen in further analysis for its interpretability (Caruana & Niculescu-Mizil, 2006) (Table 3).

-Insert Table 3 here-

Results showed that *content dependency* was the most influential factor on the impact of students' CT learning (Figure 2). However, it was its synergistic work with *CT student practice* and *context* that made a positive impact. Specifically, students in a lesson that offered *CT student practice* and learning of one subject was dependent on the other were more likely to improve their CT knowledge than lessons without *CT student practice*. For example, a PST offered facilitations regularly in their small group project on coding color sensors of a robot (as a predator) to hunt animals in camouflage in a 3rd.-grade science class, during which students recalled key concepts to explain why the hunting was un/successful. A positive *CT impact* was predicted if a lesson was embedded in students' real-world experiences and the learning of subjects was interrelated. For example, in a second-grade math class, Halloween candies were placed at various locations on a castle map, with the number of candies at each spot determined by solving specific addition and subtraction equations. Students were challenged to solve the math problems and then code a robot to navigate to the correct locations, where they would receive the corresponding number of candies as a reward.

-Insert Figure 2 here-

Subject Impact

The decision tree was fit with a maximum depth of 3 and a minimum sample per leaf of 3. Results of the model comparison showed that the decision tree classification method using the CART algorithm yielded the best result and therefore was chosen for further analysis (Table 4).

-Insert Table 4 here-

The tree showed that *content dependency* was the most important factor in determining whether an integrated CT lesson had a positive impact on students' subject content learning (Figure 3). When the learning of one subject depended on the other, it was likely to generate a positive impact on students' learning of the subject. For example, students in a second-grade science class decorated the robots as bees and code them navigate among flowers to mimic the pollination process. A non-positive impact was predominantly predicted when the learning of the two subjects was independent and lacked context. For example, the code was pre-loaded and students were introduced to coding the wave shapes in a fourth-grade science class. However, no connections were made to recall their wave properties knowledge.

-Insert Figure 3 here-

Significance

This study has both theoretical and practical significance. First, it bridges the research gap between teacher preparation and PSTs' classroom implementation on integrated CT education (Alejandro et al., 2024; Yun & Crippen, 2024), and thus enables us to provide informed suggestions for future teacher preparation programs. Second, most of the students in this study came from Title I schools, a population often facing substantial educational disparities. Our findings demonstrate that incorporating real-world contexts and connecting two subjects in learning activities significantly improved students' learning outcomes of both CT and subject content. It highlights the importance of pedagogical approaches that are not only effective but also culturally responsive and relevant to the experiences of students in Title I schools.

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Table 1

PST Training Schedule

Semester 1	
Day 1	• Presentation: Program Overview • Workshop: Makeblock® mTiny Robot Setup, Introduction, Coding • Presentation: Introduction to the State CT and Computer Science Standards
Day 2	• Presentation: Introduction to ELA Standards • Sample Lesson: Integrating CT into a 1st. Grade ELA Class • Guest Speaker: Integrating CT from Unplugged to Plugged In • Small Group Lesson Idea Development: Integrating CT into K-2 ELA class • Presentation: Introduction to SS Standards • Sample Lesson: Integrating CT into a Kindergarten SS Class • Small Group Lesson Idea Development: Integrating CT into a K-2 SS class
Day 3	• Workshop: Makeblock® mBot Neo Robot Assembling, Setup, and Coding • Sample Lesson: Integrating CT into a 4th. Grade ELA Class • Small Group Lesson Idea Development: Integrating CT into a Grades 3-5 ELA class
Day 4	• Workshop: Makeblock® mBot Neo Robot Coding • Sample Lesson: Integrating CT into a 3rd. Grade ELA Class • Seminar: Teaching a Technology Lesson with Inclusive Practices • Small Group Lesson Idea Development: Integrating CT into a Grades 3-5 SS Class
Day 5	• Small Group Lesson Development and Peer Teaching
Semester 2	
Day 6	• Guest Speaker: Why Computing Matters for Teachers • Presentation: Introduction to Science Standards • Sample Lesson: Integrating CT into a 1st. Grade Science Class • Small Group Lesson Idea Development: Integrating CT into a K-2 Science Class
Day 7	• Technology Revisit and Reinforce Workshop: Makeblock® mBot Neo • Presentation: Introduction to Mathematics Standards • Sample Lesson: Integrating CT into a 2nd. Grade Mathematics Class • Small Group Lesson Idea Development: Integrating CT into a K-2 Mathematics Class
Day 8	• Technology Revisit and Reinforce Workshop: Makeblock® mBot Neo • Sample Lesson: Integrating CT into a 4th. Grade Mathematics and Science Class • Small Group Lesson Idea Development: Integrating CT into a Grades 3-5 Mathematics and/or Science Class
Day 9	• Small Group Lesson Development and Peer Teaching

Table 2

Description of Independent Variables

Variable Name: context Definition: types of contexts upon which integrated CT practices were built Levels: their meanings with examples: • 0: integrated CT practices without a context • 1: application of one subject knowledge in another subject context, e.g., Students coded the robot (CT) to follow a story's plot sequence (English) in chronological order. • 2: an integrated CT practice was embedded in a context that was related to students' real-world experiences, e.g., coding a robot as an animal seeking shelter.
Variable Name: technology Definition: what robot was used Levels: their meanings with examples: • 0: classes that used the unplugged robot, mTiny • 1: classes that used mBot Neo
Variable Name: CT student practice Definition: whether a lesson offered students CT practice opportunities with a PST's explicit guidance and/or facilitation Levels: their meanings with examples: • 0: without a PST's explicit guidance and/or facilitation, e.g., a PST took a hands-off approach and didn't offer any feedback during students' small group practices. • 1: with a PST's explicit guidance and/or facilitation, e.g., students led small-group coding practices and a PST regularly offered constructive feedback and suggestions to support them debug problems or refine their solutions.
Variable Name: content dependency Definition: whether CT and subject knowledge were connected and applied to reach a common outcome in the integrated CT practices Levels: their meanings with examples: • 0: CT and subject knowledge were not connected • 1: CT and subject knowledge were connected, e.g., a math calculation practice took place first. Next students coded a robot to move to the destination where the correct answers were placed.

Table 3

Model Evaluation Results on the CT Impact

Methods	Accuracy	F1	Precision	Recall	AUC-ROC
Decision Tree	0.87	0.83	0.92	0.80	0.8
Random Forest	0.87	0.83	0.92	0.80	0.8
XGBoost	0.80	0.72	0.88	0.70	0.7

Table 4

Model Evaluation Results on the Subject Impact

Methods	Accuracy	F1	Precision	Recall	AUC-ROC
Decision Tree	0.92	0.87	0.95	0.83	0.93
Random Forest	0.92	0.87	0.95	0.83	0.83
XGBoost	0.92	0.87	0.95	0.83	0.83

Figure 1

Sequence of Integrated CT Lessons

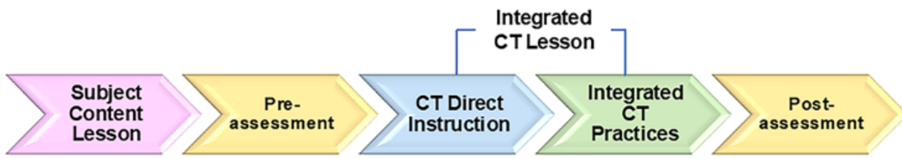

Figure 2

Decision Tree Plot on the CT Impact

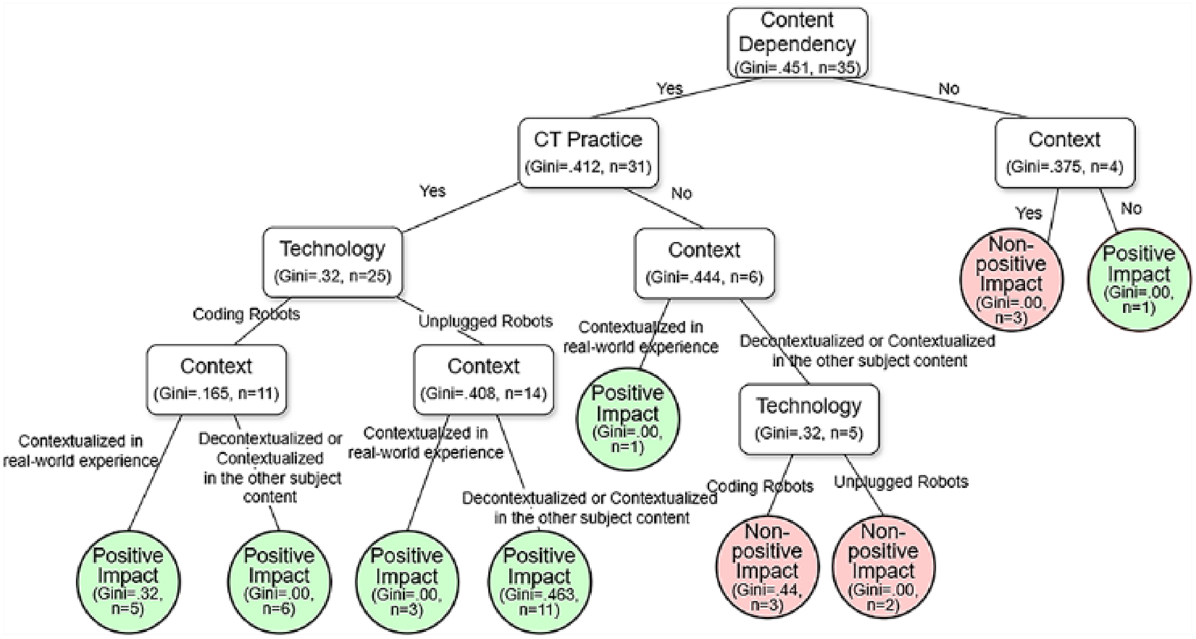

Figure 3

Decision Tree Plot on the Subject Impact