

UNIVERSITY OF EDUCATION, WINNEBA



**EFFECTS OF UNPLUGGED COMPUTATIONAL THINKING ACTIVITIES
IN MATHEMATICS ON PRE-SERVICE TEACHERS' COMPUTATIONAL
THINKING SKILLS**



SALLAH EMMANUEL KWADZO

DOCTOR OF PHILOSOPHY

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**A thesis submitted to the school of graduate studies in
partial fulfilment of the requirement for the award of
the degree of Doctor of Philosophy
(Mathematics Education)**

**Department of Mathematics Education
Faculty of Science Education**

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DECLARATION

Student's Declaration

I, **EMMANUEL KWADZO SALLAH**, hereby declare that this thesis, except quotations and references contained in published works, which have all been identified and acknowledged, is entirely my original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

Signature:

Date:

Supervisor's Declaration

We hereby declare that the preparation and presentation of this work were supervised in accordance with the guidelines for supervision of the thesis as laid down by the University of Education, Winneba.

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Signature:

Date:

Name of Supervisor: Doctor Joseph Issah Nyala

Signature:

Date:

DEDICATION

To my dear wife and children



ACKNOWLEDGEMENT

I am profoundly grateful to Almighty God for His guidance, strength, and grace throughout this PhD journey. Without His blessings, this accomplishment would not have been possible.

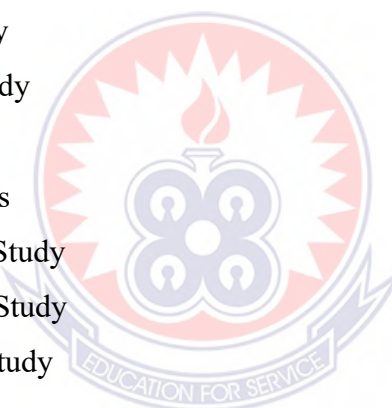
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ABSTRACT

Developing higher-order thinking skills among pre-service teachers is essential for preparing them to promote problem-solving, logical reasoning, and analytical thinking in mathematics classrooms. However, the integration of Computational Thinking (CT) in teacher education programmes remains limited, creating a need for effective instructional approaches that can enhance these competencies. This study examined the effects of Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' CT skills. The study employed a mixed-methods approach using an explanatory sequential design. A total of 87 pre-service teachers participated in the study, comprising 44 in the experimental group from E.P. College of Education, Amedzofe, and 43 in the control group from Peki College of Education. Data were collected through CT skills tests, observation guides, questionnaires, and focus group discussions. Quantitative data were analysed using descriptive statistics and independent samples t-tests, while qualitative data were analysed through inductive thematic analysis. The findings revealed that before the intervention, most pre-service teachers demonstrated emerging or developing levels of CT skills, with none attaining the proficient level. Pre-service teachers exhibited weak skills in decomposition, abstraction, and algorithmic thinking when engaging in unplugged CT mathematics tasks. Post-intervention results indicated a statistically significant difference between the experimental and control groups, suggesting that the UCTAM approach had a positive effect on pre-service teachers' CT skills. The findings further showed that the use of UCTAM enhanced conceptual understanding in mathematics, strengthened critical thinking, and improved problem-solving abilities. In addition, pre-service teachers reported increased confidence and positive attitudes towards learning mathematics. The study concludes that integrating unplugged computational thinking activities into mathematics instruction can effectively support the development of computational thinking skills among pre-service teachers and improve their engagement with mathematical problem solving.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter presents the background to the study and the statement of the problem. It states the purpose and objectives and outlines the research questions. The chapter also discusses the significance, scope, and limitations. It presents the organisation and summary of the chapter.

1.1 Background to the Study

The current pre-tertiary education reform in Ghana has introduced the standards-based curriculum (SBC), replacing the objective-based curriculum and signalling a shift towards a learner-centred and competency-based approach to teaching and learning (NPECF, 2018). The reform aims to transform the education system into a more relevant, effective, and responsive one that aligns with national development goals and global trends.

The SBC is organised around clearly defined standards that outline what learners are expected to know and be able to do at each grade level. These standards encompass essential knowledge, skills, values, and attitudes across all subjects and are supported by specific learning indicators that guide lesson planning, instructional activities, and assessment (NPECF, 2018). The SBC aims to develop well-rounded learners equipped with core competencies such as critical thinking, problem-solving, creativity, communication, collaboration, digital literacy, cultural identity, global citizenship, personal development, and leadership (NPECF, 2018). Integrating these core competencies across subjects ensures learners acquire subject-specific knowledge and essential life skills necessary to thrive in the 21st century (NPECF, 2018).

Computational thinking (CT) is a problem-solving process that involves decomposition, pattern recognition, abstraction, and algorithmic thinking (Wing, 2006). Though rooted in computer science, CT has evolved into a critical skill for all disciplines and learners. It enables individuals to break down complex tasks into manageable parts, recognise patterns, extract general principles through abstraction, and develop step-by-step solutions, much like the processes used by computers (Wing, 2020).

As the world becomes more digitally driven, computational thinking is essential for developing learners' ability to tackle problems methodically and with clarity (Angeli et al., 2016). The integration of computational thinking into mathematics instruction deepens one's understanding by linking abstract ideas to practical applications and fosters essential, transferable skills for thriving in a technology-oriented environment (Bocconi et al., 2022).

Computational Thinking (CT) can be taught through two main activities: plugged and unplugged activities. Plugged activities involve the use of digital tools, such as coding platforms and robotics kits, to help learners develop computational skills (Bocconi et al., 2022). Unplugged activities use physical games, logic puzzles, storytelling, and problem-solving tasks to teach computational thinking without the use of digital devices (Bocconi et al., 2022).

Unplugged computational thinking activities are gaining recognition, particularly in low-resource countries, where limited infrastructure restricts access to digital technologies. These activities promote equitable learning by using readily available materials to teach computational thinking (Bocconi et al., 2022; Shute et al., 2017).

For pre-service teachers, unplugged CT provides practical, hands-on experiences that help internalise key skills such as decomposition, abstraction, and pattern recognition. These skills are not developed in isolation; they are essential for effective mathematical problem-solving. Breaking down complex problems (decomposition), identifying underlying structures and similarities (pattern recognition), and focusing on relevant information (abstraction), PSTs build reasoning abilities that align with the demands of mathematical reasoning and problem-solving as emphasised in Ghana's pre-tertiary mathematics curriculum. Ghana's pre-tertiary mathematics curriculum advocates for learner-centred approaches that nurture critical thinking and problem-solving competencies, outcomes that unplugged CT directly supports.

In Ghana, teacher education focuses on activities designed to equip pre-service teachers with the competencies required to implement the Standards-Based Curriculum (SBC). Computational thinking is increasingly recognised as a critical component of this preparation, as it fosters not only technical skills but also the problem-solving, logical reasoning, and creative thinking abilities needed for effective teaching and learning of mathematics and other STEM subjects. Integrating CT into teacher education ensures that pre-service teachers can model these competencies in their classrooms, thereby supporting national educational goals.

Engaging pre-service teachers in unplugged CT activities promotes the integration of higher-order thinking skills into mathematics lessons in ways that are both pedagogically sound and contextually relevant. This method enhances their instructional confidence and fosters inquiry-based learning (Bocconi et al., 2022).

Integrating unplugged CT activities into teacher education enhances pre-service teachers' readiness to apply CT using available materials, fostering engagement and

deeper conceptual understanding. This approach aligns with Ghana's educational focus on problem-solving, critical thinking, and creativity (NPECF, 2018).

Integrating unplugged CT into pre-service teacher (PST) education programs equips pre-service teachers with innovative, learner-centred teaching strategies that enhance engagement and critical thinking. Through activities like puzzles, sorting tasks, and hands-on problem-solving, PSTs develop both content knowledge and the pedagogical skills essential for effective 21st-century teaching (Bocconi et al., 2022; Shute et al., 2017). The use of unplugged CT activities supports Ghana's educational goals of promoting inclusive and adaptable teaching methods that address the varied needs of learners across different classroom settings (MOE, 2022).

Unplugged Computational Thinking (CT) activities also support the goals of the Ghanaian mathematics curriculum, which emphasises analytical reasoning, creativity, and the practical application of concepts. These goals align closely with core CT components such as decomposition, abstraction, and algorithmic thinking (NaCCA, 2020).

Despite CT being one of the essential 21st-century skills valued in ongoing curriculum reform and a new strand of the computing curriculum, NaCCA has yet to publish guidelines for systematically integrating CT into subjects in the pre-tertiary curriculum, including mathematics. Although the curriculum promotes core competencies such as problem-solving, logical reasoning, and critical thinking, it does not provide guidelines for incorporating foundational CT elements like decomposition, abstraction, pattern recognition, and algorithmic thinking into the pre-tertiary curriculum.

The absence of guidelines for the systematic integration of CT into subjects in the pre-tertiary curriculum restricts pre-service teachers' exposure to CT-informed teaching strategies that could strengthen their understanding of mathematics and improve their development of 21st-century skills or core competencies. Since pre-service teachers will be responsible for implementing the standards-based curriculum, it is crucial to equip them with practical experiences that develop their ability to apply CT skills in meaningful and contextually relevant ways. Therefore, in order to provide pre-service teachers with an exposure to CT-informed teaching strategies to acquire and apply CT skills, the present study explored the effect of Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' computational thinking skills.

1.2 Statement of the Problem

Computational thinking has become an important skill for problem solving, logical reasoning, and systematic thinking in mathematics education (Ampadu, 2024; Dong et al., 2023). As a result, teachers are expected to possess computational thinking skills that enable them to guide learners in solving problems and developing key competencies required in the twenty-first century. Pre-service teachers therefore need adequate preparation to understand and apply computational thinking concepts in their teaching.

However, the integration of computational thinking in the curriculum of Colleges of Education in Ghana remains limited. As a result, many pre-service teachers graduate without a clear understanding of computational thinking concepts and how they can be applied in mathematics instruction (Gyamfi et al., 2025; Tsevi et al., 2024). This limits their ability to design learning activities that promote problem solving, logical

reasoning, and other key competencies expected in the school curriculum. Without adequate preparation, pre-service teachers find it difficult to engage learners in computational thinking during mathematics lessons.

Studies have shown that unplugged computational thinking activities supports the development of computational thinking skills and enhance learners' engagement in mathematics (Chan et al., 2020; Love et al., 2022; Yeni et al., 2021). However, there is limited empirical evidence on how such activities can be used within teacher education programmes in Ghana to develop pre-service teachers' computational thinking skills. This gap creates the need to investigate the effects of unplugged computational thinking activities in mathematics on pre-service teachers' computational thinking skills.

1.3 Purpose of the Study

The purpose of this study is to investigate the effect of unplugged computational thinking activities in mathematics (UCTAM) on pre-service teachers' (PSTs) computational thinking skills.

1.4 Objective of the Study

The objectives of the study are as follows:

1. To assess the computational thinking skills proficiency levels of pre-service teachers with minimal or no engagement in CT activities.
2. To assess the post-intervention computational thinking skills proficiency levels of pre-service teachers.
3. To investigate the effect of unplugged computational thinking activities on pre-service teachers' computational thinking skills proficiency levels.

4. To explore pre-service teachers' perceptions of the effectiveness of unplugged computational thinking activities in learning mathematics.
5. To identify the challenges pre-service teachers encounter in learning mathematics through unplugged computational thinking activities.

1.5 Research Questions

The study seeks to answer the following research questions:

1. What are the computational thinking skills proficiency levels of pre-service teachers with minimal or no engagement in CT activities? (RQ1)
2. What are the post-intervention computational thinking skills proficiency levels of pre-service teachers? (RQ2)
3. What is the effect of unplugged computational thinking activities on pre-service teachers' computational thinking skills proficiency levels? (RQ3)
4. How do pre-service teachers perceive the effectiveness of unplugged computational thinking activities in learning mathematics? (RQ4)
5. What challenges do pre-service teachers encounter in learning mathematics through unplugged computational thinking activities? (RQ5)

1.6 Research Hypothesis

The hypotheses formulated for this study are:

H₀₁: There is no statistically significant difference in the computational thinking skills proficiency levels of pre-service teachers taught using Unplugged Computational Thinking Activities in Mathematics (UCTAM) and those taught using the traditional instructional approach.

H₀₂: There is no statistically significant difference in the decomposition skills proficiency levels of pre-service teachers taught using UCTAM and those taught using

the traditional instructional approach.

H₀₃: There is no statistically significant difference in the pattern recognition skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach.

H₀₄: There is no statistically significant difference in the abstraction skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach.

H₀₅: There is no statistically significant difference in the algorithmic thinking skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach.

1.7 Significance of the Study

The study examines the influence of Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' computational skills to enhance their conceptual understanding and pedagogical practices. The findings contribute significantly to the field of teacher education by demonstrating the potential of computational thinking to transform the way mathematics is taught and understood. Incorporating UCTAM addresses the limitations of traditional teaching methods that often emphasise rote memorisation over the development of learners' critical thinking and problem-solving skills.

Additionally, the study will empower pre-service teachers to develop 21st-century skills, such as problem-solving, critical thinking, and collaboration, all of which are integral to students' success in contemporary society. The findings underline the importance of embedding these competencies into teacher education programs, as they align with global educational standards. Engaging in UCTAM allows pre-service

teachers to refine these skills, which can then be incorporated into their future classrooms to enhance student learning and engagement.

The study will promote educational equity by demonstrating how unplugged computational thinking activities can be used to teach computational thinking without the need for extensive technological resources. In Ghana's educational settings, where access to technology is limited, the study will provide a solution by emphasising unplugged methods, ensuring that all students, regardless of their technological access, will benefit from learning computational thinking.

The results of the study will provide valuable insights into the innovation of teacher education programs. By showing the effectiveness of UCTAM, the research will inform the development and implementation of curricula that foster both conceptual understanding and computational thinking skills in pre-service teachers. Educational leaders and policymakers will be able to use these findings to advocate for the integration of computational thinking into mathematics curricula, potentially leading to new standards and professional development initiatives in teacher education.

Moreover, the significance of this research extends to future studies, laying the foundation for further exploration into the long-term effects of unplugged computational thinking activities on teacher efficacy and student outcomes. Future researchers can build upon this work to investigate the broader implications of UCTAM, its scalability across different educational contexts, and its impact on diverse student populations.

1.8 Delimitation of the Study

The study focuses on pre-service teachers at E.P. College of Education, Amedzofe, and Peki College of Education to explore the integration of Unplugged Computational Thinking Activities in Mathematics (UCTAM) in mathematics education. Limiting the scope to these institutions allows the researcher to gain in-depth insights into the perceptions and challenges faced by pre-service teachers, offering context-specific recommendations aligned with the college's curriculum and teacher training programs. This focus ensures that the findings are relevant and practical for implementation within the educational context at E.P. College of Education, Amedzofe, and Peki College of Education, enhancing their potential impact.

The study emphasises Unplugged Computational Thinking Activities in Mathematics (UCTAM) due to the technological challenges faced by E.P. College of Education, Amedzofe, and Peki College of Education, particularly regarding limited access to digital resources. Excluding plugged computational thinking activities prioritise accessibility and practicality within the Ghanaian educational context, directly addressing the immediate needs of educators and students without reliance on advanced technological infrastructure.

Moreover, the study delimits its investigation to pre-service teacher education programs, recognising the crucial role that teacher training plays in shaping pedagogical practices. Focusing on this early stage of teacher preparation identifies opportunities for integrating computational thinking into teacher education curricula. This approach ensures that pre-service teachers are equipped with the necessary skills and knowledge to effectively teach computational thinking to their students.

Additionally, the study adopts a mixed-methods approach, recognising the complexity and multidimensionality inherent in the research topic. Integrating both quantitative and qualitative research methods provides a comprehensive understanding of the effects of unplugged computational thinking activities on pre-service teachers. This methodological choice enables triangulation of findings, capturing diverse perspectives and enhancing the validity and reliability of the research outcomes.

1.9 Limitations of the Study

The study focused exclusively on pre-service teachers enrolled in the Primary Education Programme at E.P. College of Education, Amedzofe, and Peki College of Education. While this targeted approach enabled an in-depth exploration within a specific context, it limits the generalizability of the findings to pre-service teachers in other colleges or educational settings.

Furthermore, the study investigated only the Algebra and Geometry strands of the mathematics curriculum. This narrow focus limits the applicability of the findings to other strands such as Statistics, Measurement, or Number and Operations, thereby restricting the broader implications of integrating computational thinking across the entire mathematics curriculum.

Additionally, the emphasis on Unplugged Computational Thinking Activities, while addressing technological barriers faced within these educational environments, restricted the range and depth of computational thinking experiences available to participants. The absence of digital tools limited the variety of activities implemented, potentially reducing the comprehensiveness and practical application of computational thinking concepts. Consequently, this may affect the preparedness of pre-service

teachers to integrate computational thinking into classrooms equipped with advanced technological resources.

1.10 Definition of Terms

Computational Thinking: Computational thinking is the process of approaching problems and designing solutions in a way that a computer, a human, or both can effectively execute. It involves breaking down complex problems into smaller, manageable parts, identifying patterns, devising algorithms, and using abstraction and logical reasoning to solve them.

Unplugged Computational Thinking Activities: Unplugged computational thinking refers to teaching and learning computational thinking concepts and skills without the use of digital devices or technology. It often involves hands-on activities, puzzles, games, and exercises that focus on computational concepts such as algorithms, patterns, and problem-solving strategies using physical materials.

Plugged Computational Thinking Activities: In contrast, plugged computational thinking activities utilise digital devices and technology to teach and apply computational thinking concepts. This includes activities such as coding exercises, programming simulations, and using software tools that allow learners to practice algorithmic thinking, debugging, and problem-solving in a digital environment.

Conceptual Understanding: Conceptual understanding refers to a deep comprehension of fundamental concepts, principles, and relationships within a subject area. In the context of mathematics education, it involves understanding mathematical ideas beyond procedural knowledge, including the ability to explain, apply, and connect concepts to real-world situations.

Computational Thinking Skills: Computational thinking skills encompass a range of abilities that enable individuals to think logically, algorithmically, and analytically to

solve problems. These skills include problem decomposition (breaking down problems into smaller parts), pattern recognition, algorithmic design (creating step-by-step solutions), abstraction (focusing on essential details), and debugging (identifying and fixing errors in algorithms or programs).

Digital Literacy: Digital literacy refers to the ability to use digital technology, communication tools, and networks to access, manage, integrate, evaluate, create, and communicate information effectively and responsibly in various contexts. It includes skills such as basic digital skills, internet literacy, computational thinking, and information literacy, which are essential for interacting with digital technology in a meaningful and productive manner.

Algorithm: An algorithm is a step-by-step procedure or formula for solving a problem, often implemented as a sequence of instructions in a programming language or as a set of logical operations.

Problem-Solving: Problem-solving involves using computational thinking and other cognitive processes to identify, analyse, and solve problems systematically and effectively.

Abstraction: Abstraction in computational thinking involves simplifying complex problems by focusing on the essential aspects and ignoring irrelevant details, making problem-solving more manageable and efficient.

Pattern Recognition: Pattern recognition is the cognitive process of identifying regularities, structures, or trends within a set of data or information. Computational thinking involves recognising repeating sequences, relationships, or arrangements that can inform the creation of algorithms or solutions. By identifying patterns, individuals can make predictions, develop general rules, and simplify complex problems, facilitating more efficient problem-solving and decision-making. In mathematics,

pattern recognition is a foundational skill that helps learners understand mathematical structures, relationships, and sequences, enabling them to apply learned patterns to new, unfamiliar problems.

Educational Technology: Educational technology encompasses the use of technology, digital tools, and resources to enhance teaching, learning, and assessment processes in education.

Pedagogical Strategies: Pedagogical strategies refer to the methods, techniques, and activities used by educators to facilitate learning and engage students in the educational process.

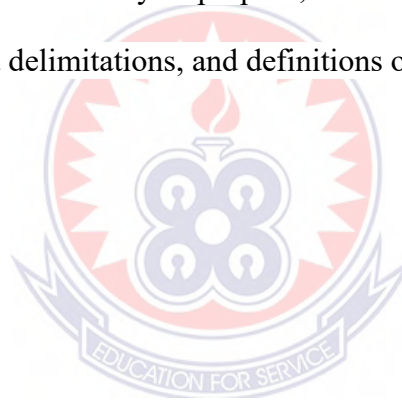
1.11 Organisation of the Study

The study is structured across five chapters, each playing a pivotal role in examining the integration of unplugged computational thinking activities among pre-service teachers. Chapter 1 serves as the introduction, providing an overarching view of the research topic, situating it within existing literature and theoretical frameworks, and defining the specific problem statement and research questions. It also highlights the study's significance by addressing gaps in current knowledge and potential contributions to mathematics education. Chapter 2 is dedicated to the theoretical framework and literature review, critically analysing prior research on computational thinking, mathematics education, and unplugged learning activities to establish a robust theoretical foundation. Chapter 3 outlines the methodology, detailing the research approach, research design, population, sample and sampling strategy, data collection methods, and analysis techniques employed to gather insights from pre-service teachers at E.P. College of Education, Amedzofe, and Peki College of Education. Chapter 4 presents the findings, offering a comprehensive analysis of collected data to elucidate the influence of unplugged computational thinking on pre-service teachers' CT skills.

Finally, Chapter 5 synthesises the study's findings, discusses their implications for educational practice and policy, proposes recommendations for future research, and concludes by emphasising the importance of integrating unplugged computational thinking in pre-service teacher education to enhance educational outcomes and prepare teachers for the digital age.

1.12 Summary of the Chapter

Chapter one provides a summary of the study on Unplugged Computational Thinking Activities in Mathematics (UCTAM) for pre-service teachers. It includes the background and context, the problem of limited integration of computational thinking in teacher education, the study's purpose, research objectives and questions, significance, scope and delimitations, and definitions of key terms.

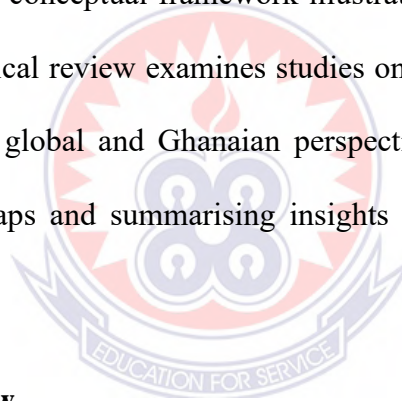


CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.0 Introduction

The literature review explores computational thinking (CT) through five key themes: theoretical review, theoretical framework, conceptual review, conceptual framework, and empirical review. The theoretical review discusses foundational learning theories that support the integration of CT in education. The conceptual review addresses the core components of CT, as well as the idea of unplugged CT activities. The theoretical framework highlights the educational theories that guide this study's perspective on teaching CT, while the conceptual framework illustrates the relationships among key constructs. The empirical review examines studies on CT integration in mathematics classrooms from both global and Ghanaian perspectives. The review concludes by identifying research gaps and summarising insights that shape the direction of the present study.



2.1 Theoretical Review

The integration of Computational Thinking (CT) into mathematics education is supported by several educational and psychological theories that explain how learners engage with, process, and apply computational skills. This review focuses on: Constructionism Theory, Constructivist Theory, Social Constructivist Theory, Cognitive Load Theory, Information Processing Theory, and Experiential Learning Theory.

2.1.1 Constructionism Theory

Constructionism, a learning theory developed by Papert (1980), emphasises learning through the active creation of tangible products. Rooted in Piaget's constructivism,

constructionism advances the idea that knowledge is most effectively constructed when learners engage in designing, building, and sharing artefacts that represent their understanding. Unlike traditional methods that prioritise rote memorisation, constructionism supports hands-on, project-based learning as a means of cognitive development. The theory is particularly relevant in the context of computational thinking (CT), which involves breaking problems into parts, recognising patterns, abstracting ideas, and developing step-by-step procedures, all of which are well-aligned with constructionist principles (Papert & Harel, 1991).

Constructionism supports the development of computational thinking among pre-service mathematics teachers by encouraging them to actively explore problem-solving strategies through meaningful creation. CT skills such as decomposition, abstraction, pattern recognition, and algorithmic thinking are strengthened when learners are engaged in tasks that involve designing instructional tools, simulating algorithms, or constructing models to represent mathematical ideas (Grover & Pea, 2013). For pre-service teachers, such experiences not only improve their own CT skills but also provide practical pedagogical strategies for fostering CT in their future classrooms. Constructionist approaches cultivate reflective thinking, which is essential for developing both content mastery and pedagogical confidence.

In Ghanaian teacher education settings, unplugged computational thinking activities offer a constructionist pathway for pre-service teachers to develop CT skills without reliance on technology. These activities use physical objects, collaborative games, storytelling, and role-playing to model computational processes. For instance, pre-service teachers may simulate sorting algorithms using index cards or teach sequences using movement-based instructions. These activities reflect constructionist ideals by

allowing learners to externalise thought processes, experiment with concepts, and iteratively refine their understanding (Bell et al., 2009). In addition, unplugged approaches enable inclusive access to CT education, especially in under-resourced teacher training institutions where digital tools are limited.

Constructionism aligns well with the Ghanaian mathematics curriculum, which emphasises problem-solving and critical thinking as core competencies. When pre-service teachers engage in constructionist activities such as creating manipulatives to teach number patterns or developing board games for geometry, they are practising mathematics instruction that embodies CT principles. These experiences foster pedagogical content knowledge and deepen their understanding of abstract mathematical concepts (Wing, 2006). Furthermore, such constructionist engagements prepare teachers to move beyond chalk-and-talk methods, promoting learner-centred strategies that resonate with current curriculum reforms aimed at competency-based education in Ghana.

Constructionism provides a theoretical and practical foundation for embedding computational thinking in Ghana's teacher education programs. Engaging pre-service teachers in artefact-based learning promotes active knowledge construction, creative problem-solving, and the development of transferrable teaching strategies. These outcomes are especially critical in a context where teaching resources are scarce and there is a growing demand for 21st-century skills integration in mathematics classrooms. Incorporating constructionist approaches through unplugged CT tasks equips pre-service teachers with the tools to innovate within constraints, making CT integration both sustainable and culturally relevant (Aboagye et al., 2022).

2.1.2 Constructivist Theory

Constructivist theory, rooted in the works of Piaget (1950) and later expanded by Jerome Bruner and Lev Vygotsky, emphasises that learners construct their understanding and knowledge through experiences and reflection. Piaget's cognitive constructivism highlights the importance of individual discovery and schema development, while Vygotsky's social constructivism underlines the role of interaction and cultural tools in learning (Vygotsky, 1978). In mathematics education, constructivism encourages the use of inquiry-based, learner-centred pedagogies that allow students to actively build their understanding of concepts rather than receive them passively (Fosnot & Perry, 2005). The theory provides a foundational lens for the development of computational thinking (CT) skills, which require learners to engage in deep, reflective problem-solving and reasoning processes.

Computational thinking, as defined by Wing (2006), involves the mental processes used in formulating problems and expressing solutions in a way that a computer or a human can understand. Constructivist environments support the development of CT by creating opportunities for learners to engage with problems in authentic contexts, experiment with ideas, and construct their algorithms and strategies (Barr & Stephenson, 2011). These include decomposition (breaking complex tasks into simpler steps), pattern recognition, abstraction, and algorithmic thinking. Pre-service teachers benefit from these constructivist activities because they allow for exploration, failure, and iteration, key components of effective CT instruction (Grover & Pea, 2013). Moreover, constructivist practices encourage metacognition and self-regulation, both essential in CT and mathematics learning (Grover & Pea, 2013).

In pre-service teacher education, constructivist methods equip pre-service teachers with practical tools and pedagogical content knowledge necessary to integrate CT in the mathematics classroom. Engaging in collaborative problem-solving, lesson design, and reflective discussion, pre-service teachers learn how to adapt CT concepts into lessons that foster deeper understanding (Yadav et al., 2014; Weintrop et al., 2016). These activities align with the goals of competency-based curricula, such as Ghana's recent curriculum reforms, which emphasise creative thinking, critical reasoning, and problem-solving (NaCCA, 2019). Constructivist approaches help pre-service teachers learn by doing, designing sorting algorithms with manipulatives or developing classroom simulations of real-world mathematical problems, which translates to more meaningful teaching and learning practices in their future classrooms.

One of the most practical applications of constructivist theory in developing CT is through unplugged activities, which require no computers but still emphasise core computational processes (Bell et al., 2009). These are particularly useful in the context of Ghana, where access to technology is limited. Constructivism encourages learners to build their understanding using physical materials, drawings, role-plays, or games to model computational thinking principles. For example, an unplugged activity on algorithms may involve students organising steps for cooking a meal or planning a route through a maze. These concrete, interactive engagements make abstract CT concepts accessible and meaningful, particularly for pre-service teachers in low-resource environments (Taub et al., 2012; Brackmann et al., 2017).

The integration of CT into mathematics education under a constructivist framework empowers pre-service teachers to shift from traditional didactic methods to active, learner-centred pedagogies. Constructivist practices align well with the Ghanaian

mathematics curriculum, which encourages the use of manipulatives, contextual tasks, and cross-disciplinary learning (NaCCA, 2019). Teachers trained in constructivist CT approaches are more likely to design lessons that engage learners in exploration, reasoning, and collaborative problem-solving. Furthermore, constructivism supports the development of reflective practitioners who can continuously adapt their teaching based on learners' needs (Jonassen, 1999). This positions constructivist theory as a crucial underpinning for embedding CT in pre-service mathematics teacher education in Ghana and similar contexts.

2.1.3 Social Constructivist Theory

Social constructivist theory, prominently developed by Lev Vygotsky (1978), posits that learning occurs as a result of social interaction and shared experiences. Unlike Piaget's cognitive constructivism, which emphasises individual discovery, social constructivism stresses the importance of collaboration, dialogue, and cultural tools in the learning process. According to Vygotsky, learners internalise knowledge through mediated experiences, especially when interacting with more knowledgeable others within their Zone of Proximal Development (ZPD). In the context of pre-service teacher education, social constructivism underpins instructional approaches that encourage collaborative problem-solving, peer discussions, and scaffolded tasks, which are also fundamental elements of computational thinking (CT).

Computational thinking involves key processes such as decomposition, abstraction, pattern recognition, and algorithmic thinking (Wing, 2006). These skills are not only cognitive but also socially negotiated when learners discuss problems, justify strategies, and reflect on outcomes together. Social constructivist environments facilitate CT development by allowing learners to exchange ideas, correct misconceptions through

peer explanations, and co-construct algorithms or problem-solving strategies (Grover & Pea, 2013). Activities such as pair programming, group debugging, or collaborative unplugged games embody social constructivist principles while fostering computational habits of mind (Barr & Stephenson, 2011).

In pre-service teacher education, social constructivism is especially powerful in preparing future mathematics teachers to model collaborative, interactive learning in their classrooms. When pre-service teachers participate in inquiry-based, group-focused CT tasks, they learn both CT content and how to facilitate such learning for their pupils (Yadav et al., 2014). This is particularly important in settings like Ghana, where collaborative teaching strategies are encouraged by curriculum reforms (NaCCA, 2019). Through social learning structures, pre-service teachers develop communication skills, cooperative planning abilities, and a deeper understanding of CT concepts and how to teach them meaningfully in mathematics classrooms.

Social constructivist theory aligns well with unplugged computational thinking activities, which are low-tech, hands-on, and inherently social. These include card-sorting tasks, group-based simulations, storytelling with algorithmic rules, and physical games that represent logical flow or conditionals (Bell et al., 2009). In resource-constrained contexts, such as many Ghanaian teacher training colleges, these cost-effective, discussion-rich activities serve dual purposes: they build CT skills and foster collaborative learning habits. As learners engage in group tasks, they negotiate meaning, share strategies, and reflect collectively, processes that social constructivists regard as central to deep understanding (Vygotsky, 1978; Brackmann et al., 2017).

Integrating CT within the mathematics curriculum through a social constructivist lens encourages learners to approach problems flexibly, collaborate meaningfully, and build

transferable skills such as logical reasoning and critical thinking. For pre-service mathematics teachers in Ghana, this means moving beyond rote learning to engage in socially embedded inquiry-based instruction. They are encouraged to design and integrate lessons where discussion, group reasoning, and co-construction of knowledge are prioritised. As such, the social constructivist theory provides a robust foundation for embedding computational thinking into mathematics instruction and equipping pre-service teachers with the pedagogical strategies necessary to foster 21st-century skills in learners.

2.1.4 Cognitive Load Theory

Cognitive Load Theory (CLT), first proposed by Sweller in the 1980s, focuses on the limitations of working memory during learning processes. CLT suggests that human cognitive architecture comprises a limited working memory and an unlimited long-term memory (Sweller, 1988). The theory posits that instructional design should optimise the load on working memory to enhance learning effectiveness. This can be achieved by reducing extraneous cognitive load, managing intrinsic load, and promoting germane load, which directly contributes to long-term learning. When applied to computational thinking (CT), CLT emphasises how problem-solving activities related to CT, such as algorithm design or abstraction, can be better understood by minimising cognitive overload, allowing learners to focus on developing critical thinking skills.

Computational thinking (CT) involves breaking down complex problems into simpler components (decomposition), identifying patterns, abstracting general rules, and developing algorithms to solve problems. Decomposition and abstraction, which are central to CT, can present challenges to learners due to the intrinsic cognitive load required to process complex information. According to CLT, when these tasks exceed

the cognitive load capacity, learners may struggle to effectively apply CT strategies (Mayer, 2009). Therefore, teachers need to be mindful of task complexity and provide appropriate scaffolding to help students manage their cognitive load. This is especially crucial in unplugged activities where students engage in hands-on problem-solving tasks without the aid of computers, thus relying on mental models and requiring a careful balance between challenge and cognitive capacity.

A key strategy for managing cognitive load is through the use of worked examples, scaffolding, and chunking. Worked examples break down problems step by step, which can help reduce the intrinsic cognitive load (Sweller, 2006). In the context of computational thinking, presenting students with guided examples of algorithmic steps can help them understand problem-solving procedures before requiring them to design their own solutions. Furthermore, scaffolding CT tasks allows learners to gradually build competence, starting with simpler problems and moving to more complex ones. In unplugged computational thinking activities, scaffolding can take the form of group discussions, peer learning, and step-by-step instructions to reduce cognitive overload, thereby enabling learners to progressively enhance their computational skills (Tharp & Gallimore, 1988).

For pre-service teachers, understanding how to manage cognitive load during CT instruction is vital. Teachers must design instructional activities that reduce extraneous cognitive load, such as minimising distractions or simplifying instructions, to help students focus on the core aspects of computational thinking. Additionally, conceptual understanding of computational thinking can be facilitated by breaking down CT tasks into manageable chunks that align with students' cognitive capabilities (Paas et al., 2003). In teacher education programs, especially those based in resource-constrained

settings like Ghana, pre-service teachers can be trained to model cognitive load management for their future students. This approach will help pre-service teachers use unplugged CT activities effectively, ensuring that their students can learn to apply computational thinking strategies without becoming overwhelmed by cognitive overload.

An important consideration in applying CLT to computational thinking is ensuring that tasks are appropriately challenging while also being accessible. Too simple tasks might lead to low engagement, while overly complex tasks can cause cognitive overload, leading to disengagement or frustration (Sweller, 2006). In pre-service teacher education, activities such as pair programming, algorithm design challenges, and mathematical problem-solving scenarios must be carefully designed to match the cognitive capacity of students. Furthermore, interactive discussions and feedback can play a critical

2.1.5 Information Processing Theory

Information Processing Theory (IPT), a cognitive theory of learning developed in the 1950s and 1960s, likens the human mind to a computer, suggesting that the brain processes information through a series of stages, including attention, encoding, storage, and retrieval (Atkinson & Shiffrin, 1968). The theory focuses on how information is processed, stored, and retrieved from memory, emphasising mental models, cognitive structures, and problem-solving strategies. In relation to computational thinking (CT), IPT provides a framework for understanding how learners process and manipulate information when engaging in tasks that require abstraction, decomposition, algorithmic thinking, and pattern recognition (Wing, 2006). As learners engage in

computational thinking tasks, IPT can help explain how they encode problem-solving strategies, store them in long-term memory, and retrieve them to apply to new contexts.

Computational thinking involves problem decomposition, pattern recognition, abstraction, and algorithm design, all of which are cognitive processes that align closely with the stages outlined in Information Processing Theory (Anderson, 2015). In IPT, decomposition is viewed as the ability to break complex problems into simpler, manageable parts, which mirrors the first step in computational thinking (Grover & Pea, 2013). In computational tasks, the pattern recognition process involves identifying patterns or regularities in data, which can then be abstracted or generalised for more efficient problem-solving (Wing, 2006). IPT suggests that schemas (mental models) are built and refined through repetition and practice. As learners recognise patterns, these schemas evolve and become more sophisticated, improving problem-solving strategies over time. Linking information processing with computational thinking, learners develop the cognitive structures necessary to approach complex tasks, using algorithms and abstractions that were previously encoded and stored.

A core concept of Information Processing Theory is the idea of encoding information into long-term memory and later retrieving it when necessary (Baddeley, 1992). In computational thinking tasks, learners are often tasked with encoding and storing complex algorithmic steps, rules, and strategies, which must be retrieved when applying them to solve similar problems in the future. Practice and repetition are essential to this process; as learners work on unplugged computational thinking activities (e.g., group problem-solving tasks or computational games), they strengthen the neural pathways that allow for the retrieval of these problem-solving strategies (Sweller, 2006). For example, when students solve puzzles involving sequence recognition or algorithmic

patterning, the processes of encoding and retrieving information help reinforce their computational thinking abilities. In pre-service teacher education, providing consistent opportunities for encoding and retrieving problem-solving processes is vital for long-term retention of computational thinking skills.

In pre-service teacher education, particularly in mathematics, Information Processing Theory suggests that teachers must create instructional environments that promote the active encoding and retrieval of computational thinking skills. For instance, when teaching algorithm design or abstraction in mathematics classrooms, instructors can use strategies such as step-by-step problem-solving guides, repetitive practice, and interactive simulations to help learners build and strengthen their cognitive models. Activities that allow for frequent rehearsal of computational thinking concepts, like unplugged computational thinking games, are effective in reinforcing the storage of these concepts in long-term memory. Furthermore, designing scaffolded tasks that challenge students to retrieve prior knowledge while learning new content can enhance cognitive connections and foster deeper understanding. This method helps pre-service teachers understand how to apply Information Processing Theory to make learning CT concepts more accessible and applicable to real-world classroom contexts.

Unplugged computational thinking activities, those that do not require computers or digital tools, provide a rich context for exploring Information Processing Theory. These activities often involve physical manipulation of objects, group-based problem-solving, and abstract reasoning, all of which require learners to encode and retrieve computational thinking concepts. For example, tasks that involve grouping shapes, sorting numbers, or sequencing tasks provide opportunities for learners to practice and retrieve knowledge of computational strategies like pattern recognition and

decomposition. According to IPT, engaging in hands-on unplugged activities allows learners to actively encode their understanding of computational concepts and create the necessary mental models for future problem-solving tasks. This approach helps in consolidating knowledge and improving retrieval efficiency during future computational thinking challenges (Bell et al., 2009).

2.1.6 Experiential Learning Theory

Experiential Learning Theory (ELT), as proposed by Kolb (1984), posits that learning is a process whereby knowledge is created through the transformation of experience. The model emphasises active engagement, suggesting that learners must be involved in a cycle of concrete experience, reflective observation, abstract conceptualisation, and active experimentation. Kolb's theory underlines the importance of reflection and application, encouraging educators to design learning environments that provide hands-on experiences followed by opportunities for learners to reflect and apply what they have learned. In relation to computational thinking, ELT supports the idea that learners develop a deeper understanding of abstract computational concepts, such as abstraction, decomposition, and algorithmic thinking, when they are actively involved in doing and reflecting.

Experiential learning provides a powerful foundation for developing computational thinking skills, especially through unplugged activities that engage learners in real-world problem-solving tasks. When learners are given concrete tasks, such as sorting objects, creating sequences, or designing flowcharts, they engage in concrete experiences that are essential to the ELT cycle. Reflection on these experiences allows for conceptual abstraction, such as recognising underlying patterns or principles. These insights can then be tested and refined through active experimentation, helping learners

internalise computational thinking processes. Studies have shown that hands-on, iterative learning enhances not only students' problem-solving skills but also their ability to transfer these skills across domains (Grover & Pea, 2013; Yadav et al., 2016). In the context of pre-service teacher education, ELT emphasises the need for practice-based learning environments where future teachers engage in the kinds of learning they are expected to foster. For example, teaching computational thinking through unplugged activities aligns perfectly with Kolb's model. Pre-service teachers can participate in CT activities, reflect on the learning process, derive abstract principles (such as how decomposition helps in problem-solving), and then apply these principles in designing and teaching their lessons. This experiential cycle fosters metacognition, allowing future teachers not only to understand CT skills but also to reflect on effective teaching methods and student responses. It also supports professional identity formation, as teachers begin to see themselves as facilitators of 21st-century skills (Kotsopoulos et al., 2017).

Mathematics is an ideal domain for integrating experiential learning with a focus on computational thinking. Activities such as building number patterns with physical manipulatives, simulating algorithms with human instructions, and exploring geometric decomposition tasks provide opportunities for concrete engagement. For example, asking learners to physically sort shapes by attributes fosters pattern recognition and abstraction. Reflecting on these actions leads to conceptual understanding, which can then be tested in new, more abstract mathematical contexts. When integrated with unplugged CT strategies, ELT allows students to experience math and computation tangibly, enhancing both conceptual understanding and problem-solving fluency (Bell et al., 2009; Resnick, 2007).

Adopting Experiential Learning Theory in CT instruction suggests a shift from teacher-centred lectures to learner-centred, activity-rich environments. Teachers are encouraged to provide problem-based tasks, allow space for collaborative reflection, and design opportunities for application and experimentation. For example, computational thinking lessons in the Ghanaian basic education curriculum can be enriched by incorporating unplugged activities such as creating decision trees, solving logic puzzles, or exploring real-life sequencing events. These methods give learners direct experience with abstract concepts, making them more accessible and meaningful. This approach is especially beneficial for pre-service teachers, who benefit from modelling and practising experiential strategies that they can later integrate into their classrooms.

2.2 Theoretical Framework

The study is underpinned by two complementary theoretical perspectives: Constructionism Theory and Experiential Learning Theory. These frameworks were selected to provide a robust lens through which the effect of unplugged CT activities in mathematics (UCTAM) on pre-service teachers' levels of computational thinking (CT) can be examined. Both theories are aligned with the pedagogical and epistemological underpinnings of unplugged activities, particularly in active learning, knowledge construction, and the cultivation of higher-order thinking.

Constructionism, introduced by Papert (1980), extends Piaget's constructivist theory by asserting that learning occurs most effectively when individuals are engaged in the active construction of tangible artefacts that are personally meaningful and socially shareable. It posits that learners internalise knowledge more deeply when they build,

manipulate, and refine external representations of their ideas, especially through projects that encourage iterative design, problem-solving, and creativity.

This theory directly aligns with the unplugged activities, which promote physical interaction with concepts traditionally delivered through abstract instruction. In this study, pre-service teachers engage with mathematical and computational ideas by physically modelling sequences, creating algorithms using manipulatives, or solving logic puzzles without the use of digital devices. These activities support the constructionist idea of learning-by-making, thereby enabling learners to construct their understanding of complex concepts in mathematics and CT through iterative experimentation (Papert & Harel, 1991; Kafai & Resnick, 1996).

Furthermore, constructionism supports the development of CT dimensions such as abstraction, decomposition, pattern recognition, and algorithmic thinking, each of which is central to the unplugged activities. By emphasising the learner's role as a creator rather than a passive recipient, the theory fosters autonomy, cognitive engagement, and deep conceptual change, all of which are essential outcomes for pre-service teacher education.

Experiential Learning Theory (ELT), developed by Kolb (1984), provides an equally compelling rationale for the pedagogical design of unplugged activities. ELT conceptualises learning as a dynamic process whereby knowledge is created through the transformation of experience. The theory delineates a four-stage cyclical model: Concrete Experience, Reflective Observation, Abstract Conceptualisation, and Active Experimentation, which together describe how individuals learn through direct engagement and reflective practice.

Unplugged activities are structured to align with this model. For instance, when pre-service teachers participate in hands-on tasks such as classifying numbers on a 1–100 chart, they are immersed in concrete experiences. They then engage in reflective observation by discussing the logic behind their processes and analysing errors or alternative strategies. This is followed by abstract conceptualisation, where they make connections between the activity and the underlying mathematical or computational principles. Finally, through active experimentation, they apply what they have learned in new or extended problem-solving contexts.

The experiential learning cycle ensures that knowledge is not only encountered but also internalised through critical reflection and meaningful application. This is particularly relevant in teacher education, where reflective practice is central to pedagogical growth. Moreover, the emphasis on experience-based learning helps pre-service teachers develop the pedagogical content knowledge (PCK) required to facilitate active, inquiry-driven learning environments for their future students.

The combined application of Constructionism Theory and Experiential Learning Theory offers a theoretically sound and pedagogically relevant framework for investigating the effect of UCTAM on PSTs' levels of computational thinking. While constructionism provides a foundation for understanding how learners build knowledge through creating artefacts and engaging with tangible problems, experiential learning theory emphasises the cyclical, reflective process through which learning is deepened and extended.

Pre-service teachers not only need to develop domain-specific skills but must also internalise effective teaching practices. These theories jointly highlight the importance of active participation, reflective inquiry, knowledge construction, and application in

authentic contexts, all of which are embedded in the design and delivery of unplugged activities.

2.3 Conceptual Review

This section explores the key concepts underpinning this study, namely: Computational Thinking (CT), Plugged Activities, Unplugged Activities, and the core components of unplugged activities: Decomposition, Pattern Recognition, Abstraction, and Algorithmic Thinking.

2.3.1 Computational Thinking

The concept of "computational thinking" has deep roots in the history of computer science, dating back to its earliest days. Even though the formal term was coined in the late 20th century, its foundational principles can be traced back to the emergence of the first computers in the 1940s. During this period, fundamental concepts such as algorithmic thinking and problem decomposition were already inherent to the discipline (Brookshear, 1985). However, it wasn't until Jeannette Wing's groundbreaking work in 2006 that computational thinking gained widespread recognition as a versatile problem-solving activity applicable across diverse domains beyond computer science (Wing, 2006). Wing's influential contribution sheds light on the significance of computational thinking as a cognitive framework, highlighting its importance in navigating intricate challenges and fostering logical reasoning skills. This recognition propelled computational thinking into the spotlight, positioning it as a vital skill set for navigating an increasingly digital and interconnected world. Despite its recent formalisation, computational thinking's influence on problem-solving methodologies has been profound and enduring over the decades.

Computational thinking goes beyond mere problem-solving; it embodies a comprehensive mental framework that equips individuals with the tools to address complex issues systematically and logically (Wing, 2006). At its essence, computational thinking emphasises the crucial skill of problem framing, ensuring that challenges are approached in a manner conducive to effective resolution through the application of computational steps and algorithms (Wing, 2006). Essentially, computational thinking urges individuals to adopt the mindset of a computer scientist, enabling them to deconstruct daunting problems into manageable components. Through this process, individuals can formulate precise instructions or algorithms to steer their problem-solving journey, ultimately leading to the attainment of desired outcomes. These multifaceted activities for problem-solving not only enhance individuals' capacity to navigate intricate tasks but also cultivate the development of analytical thinking skills essential for success in an increasingly technology-driven world.

2.3.2 Plugged Computational Thinking Activities

Plugged CT activities involve the integration of digital tools, such as programming platforms, simulations, and educational software, to develop learners' ability to solve problems algorithmically. This conceptualisation aligns with Wing's (2006) seminal definition of CT as "a fundamental skill for everyone" that includes core practices such as decomposition, pattern recognition, abstraction, and algorithm design.

Plugged CT activities distinguish themselves from unplugged CT activities by emphasising interaction with digital interfaces and coding environments that enable users to visualise, simulate, and manipulate problem elements dynamically. These tools foster engagement by providing immediate feedback, personalised pacing, and opportunities for iterative refinement (Grover & Pea, 2013). Plugged CT activities offer

a structured space where learners' cognitive processes are extended through technology-mediated representations.

2.3.3 Unplugged Computational Thinking Activities

Unplugged CT activities refer to the use of physical, hands-on activities, without the direct use of computers or digital devices to teach computational concepts and problem-solving skills. The approach was popularised through the Computer Science Unplugged initiative, which demonstrated that core computational ideas such as algorithms, sorting, pattern recognition, and binary representation can be taught through games, puzzles, and interactive tasks (Bell et al., 2009). Rooted in constructivist theory, unplugged activities provide learners with opportunities to manipulate tangible objects and engage in kinesthetic learning, thereby making abstract CT concepts more accessible, particularly for younger learners and novices (Wing, 2006; Papert, 1980).

2.3.4 Components of Unplugged Activities

This section explores the core components of unplugged computational thinking activities: decomposition, pattern recognition, abstraction, and algorithmic thinking, and their role in enhancing problem-solving skills and conceptual understanding in mathematics education. Integrating these components into mathematics teaching and learning allows learners to strengthen their logical reasoning and critical thinking, fostering a deeper understanding of mathematical concepts through hands-on, interactive learning experiences.

2.3.5 Decomposition

In unplugged computational thinking, decomposition reigns supreme. It is a strategic activity that meticulously dismantles intricate problems into smaller, more readily grasped sub-problems. This meticulous breakdown fosters a deeper comprehension of

the fundamental components and their intricate interplay (Jiang et al. 2023). Within the computer science domain, decomposition serves as the cornerstone for crafting well-structured programs. By meticulously dissecting programs into independent functions, each meticulously focused on a specific task, decomposition demonstrably enhances code readability and operational efficiency (Charitsis et al. 2023). This "divide-and-conquer" strategy transcends the digital realm, proving equally applicable to real-world problem-solving endeavours. By decomposing complex challenges, we are empowered to pinpoint root causes and meticulously craft targeted solutions for each sub-problem. These meticulously crafted, step-by-step activities ultimately culminate in a comprehensive solution for the overarching challenge (Lee et al., 2023). Decomposition essentially transforms seemingly insurmountable situations into a series of achievable steps, thereby empowering individuals to approach activities and problems with a heightened sense of control and focus (Lee et al., 2023).

Delal and Oner (2020) explored the effect of unplugged computing activities on enhancing computational thinking (CT) skills among 6th-grade students. Their study focused on developing skills such as problem-solving, algorithmic thinking, pattern recognition, decomposition, and abstraction, all integral to CT. Activities were structured around the Bebras challenge, encompassing tasks of varying difficulty levels aimed at promoting these CT processes. Pre-test and post-test assessments based on Bebras tasks showed significant improvements in students' overall CT skills following the intervention. Their study highlighted the effectiveness of unplugged computing activities in fostering a range of CT skills crucial for modern problem-solving and informatics among middle school students.

Threekunprapam and Yasri (2020) conducted a study to explore the patterns of computational thinking (CT) development among high school students engaged in unplugged coding activities using the 3s activities for self-directed learning. Their study developed unplugged coding activities based on flowcharts, focusing on sequences, repetitions, inputs & variables, conditions, and loops with conditions across five missions. Data collection involved video recordings and observations of 120 high school students, revealing a thematic progression in CT development from initial to partial and fully developed stages. Different abilities in applying computer science concepts were observed, influencing the expression of CT skills during mission completion, particularly emphasising decomposition skills in effectively breaking down tasks. Additionally, the study introduced the 3s self-directed learning activities, comprising self-checks and self-debugging in pairs, along with scaffolding, to support CT development. The integration of the 3s model with unplugged coding activities is recommended for effectively fostering CT skills among high school learners.

Merino-Armero et al. (2022) conducted a study to explore the effect of unplugged activities on introducing computational thinking (CT) in cross-curricular teaching, specifically in the Social Sciences area among sixth-grade students. The study addressed various activities to integrate CT into school curricula amidst economic and pandemic-related challenges. Using a quasi-experimental design, the researchers integrated an unplugged intervention where 14 students engaged in programming an imaginary robot on paper, contrasting with a control group of 31 students attending regular classes. Results indicated a significant increase in CT development ($p < 0.001$) with a large effect size ($d = 1.305$) among the intervention group, while academic achievement did not differ between groups. This study underscores the efficacy of

unplugged CT teaching methods in non-STEM subjects, suggesting that students can enhance their CT skills while mastering traditional academic content.

Piedade and Dorotea (2023) examined the impact of Scratch-based activities on the computational thinking skills and conceptual understanding of 4th-grade students over one school year. The study included 189 students from two school clusters divided into experimental and control groups. Results revealed statistically significant differences between the groups, with students in the experimental group (engaged in Scratch activities) achieving higher scores compared to those in the control group (not exposed to Scratch). These findings underscore the effectiveness of Scratch-based activities in enhancing computational thinking skills among 4th-grade students.

Vieira et al. (2023) investigated the integration and outcomes of a nationwide professional development program aimed at integrating computational thinking (CT) into the K-12 curriculum for lower and upper secondary school teachers. Recognising the importance of CT skills, including decomposition, in a global society and the challenges associated with teaching these skills, the program included both unplugged activities to scaffold learning and plugged activities using the Micro device, following a use-modify-create progression. Their study employed a quasi-experimental design to compare the CT skills of students taught by program participants against those in a control group. Results indicated a positive effect of the integrated learning activities on student CT knowledge and skills, particularly in the area of decomposition, which remained significant after controlling for school context and student gender. This study highlights effective activities for integrating CT activities, focusing on decomposition skills, in a developing country context and demonstrates their efficacy in a large-scale study.

Mumcu et al. (2023) explored the integration of decomposition skills within mathematics education through an unplugged computer science (CS) activity. Their study aimed to examine how computational thinking (CT), particularly decomposition, can be integrated into mathematics classrooms using unplugged CS methods. The researchers developed an activity focused on efficiently and accurately transmitting data between a transmitter and receiver, incorporating CT components essential for problem-solving and algorithmic thinking. Pre-service teachers were trained to integrate this unplugged CS activity, which involved 80 students. Their study underscores the role of decomposition skills in enhancing CT within mathematics education, offering practical insights into classroom integration and participant perceptions.

Piedade and Dorotea (2023) conducted a study to evaluate the impact of Scratch-based activities on 4th-grade students' computational thinking (CT) skills over one school year. Their research involved 189 students from two school clusters, divided into experimental and control groups. Their experimental group engaged in Scratch-based activities, while the control group did not. The Beginners Computational Thinking Test by Zapata-Cáceres et al. (2020) was used to assess students' CT knowledge. Results showed statistically significant differences between the groups, with students in the experimental group demonstrating higher scores on the CT test compared to the control group. Specifically, the study highlighted improvements in computational thinking skills such as decomposition, reinforcing the effectiveness of Scratch-based activities in promoting comprehensive CT development among elementary school students.

Sun et al. (2024) conducted an 8-week quasi-experimental study to evaluate the effectiveness of unplugged programming activities in enhancing the computational

thinking (CT) skills, particularly decomposition skills, of 7th-grade students in China. The study addressed challenges such as limited programming experience and unequal access to programming education resources. It involved 93 participants, with 62 students in two experimental groups engaged in unplugged activities and 31 students in a control group without such activities. The results showed that unplugged programming significantly improved students' decomposition skills, a core component of CT. While students' mathematical performance and prior programming experience influenced their overall CT skills, these factors did not affect the gains in decomposition skills through unplugged activities. The findings suggest that unplugged programming activities effectively develop decomposition skills in all students, regardless of their learning background. This study highlights the potential of unplugged programming as a means to enhance decomposition skills and CT in junior high school students, offering valuable insights for improving CT education.

Based on the literature review, unplugged computing activities significantly enhance computational thinking (CT) skills, particularly in problem-solving, algorithmic thinking, and pattern recognition. These activities effectively develop CT components such as decomposition and abstraction. They foster the progression of CT skills across different educational levels and are effective in both STEM and non-STEM subjects.

2.3.6 Pattern Recognition

Pattern recognition, a fundamental pillar of problem-solving, lies in the ability to identify recurring elements, similarities, and regularities within a single problem or across different situations (Stephens & Kadjevich, 2020). It is like having a superpower that allows you to see through the surface complexity and uncover the underlying order that governs the challenge at hand (Stephens & Kadjevich, 2020). This deeper

understanding fosters more effective activities for tackling the problem. By recognising patterns, we can identify common themes that transcend the specifics of the situation. This, in turn, empowers us to develop generalised solutions, reusable strategies that can be effectively applied to a broader range of scenarios.

Chan et al. (2020) investigated the effectiveness of integrating computational thinking (CT) into mathematics classrooms, specifically on the topic of number patterns, in a Singapore secondary school using a quasi-experimental design. Their study involved 106 lower secondary students, with 70 in the experimental group and 36 in the control group. The experimental group participated in both unplugged Math+ C activities and plugged Math+ C activities using a spreadsheet, while the control group received traditional instruction without intervention. Both groups took a pretest before instruction and a posttest afterwards. Data analysis using a two-way mixed-design ANOVA revealed a significant main effect of the pretest and posttest between the experimental and control groups, but no significant main effect of the groups or interaction between tests and groups. These findings contribute to the understanding of CT integration in mathematics instruction.

Rosali and Suryadi (2021) analysed 8th-grade students' computational thinking skills in Number Patterns lessons during the COVID-19 pandemic through a qualitative-descriptive study involving four students in Makassar. Using essay-type tests and interviews, they found that all students met the first indicator of problem decomposition, and one met the second; all demonstrated pattern recognition; three showed abstraction and generalisation; all met the first indicator of algorithmic thinking, and two met the second. Their findings indicate generally low computational thinking skills, highlighting the need for a structured educational framework to improve

these skills. This study provides valuable insights for designing and assessing computational thinking skills in pre-service teachers, emphasising the importance of detailed indicators and considering external factors, which can enhance your research on unplugged computational thinking activities in mathematics education.

Chan et al. (2021) conducted a study to investigate the impact of computational thinking (CT) activities, specifically focusing on number patterns, on the learning performance of secondary students in Singapore. The research utilised a quasi-experimental design involving 106 Secondary One students (approximately 13 years old) from a secondary school, with 70 students assigned to the experimental group and 36 to the control group. The experimental group participated in CT-infused activities both on- and off-computer, while the control group did not receive such interventions. Pre-tests and post-tests were administered to both groups, and the data were analysed using the partial credit version of the Rasch model. While overall results did not show significant improvement in mathematics learning performance between the experimental and control groups, individual student analysis revealed notable improvements among some participants in the experimental group. This study contributes empirical evidence regarding the integration of CT practices, including pattern recognition, in the mathematics classroom, suggesting potential benefits for enhancing specific aspects of student learning despite mixed overall findings.

Luo et al. (2022) examine elementary computational thinking (CT) instruction and assessment using unplugged computational thinking activities from a learning trajectory (LT) perspective. Their research aims to fill the gap in empirical studies on how elementary students develop and apply CT in problem-solving. Utilising LTs, which outline hypothesised learning goals, progressions, and activities in CT concept

areas such as sequence, repetition, conditionals, and decomposition, their study integrated eight mathematics-CT integrated lessons aligned with U.S. national mathematics education standards. Their study employed basic interpretive qualitative methods, including cognitive interviews with third- and fourth-grade students ($n = 22$), to gain deeper insights into students' expressions of CT. Participants' articulations of CT were analysed using a priori codes derived from LT learning goals and mapped accordingly. Their results showcased a spectrum of CT applications in problem-solving, including precise problem-solving instructions, pattern recognition, and arithmetic problem decomposition, all through unplugged activities. The empirical data collected contributes theoretical insights by offering initial evidence supporting the hypothesised learning goals and progressions within LTs. By focusing on unplugged activities, the study emphasises the potential of integrating CT into elementary education without relying on technology, thereby broadening access and engagement in computational thinking.

Waris and Pakistani (2023) conducted an experimental study aimed at enhancing computational thinking skills among elementary school students, specifically focusing on 7th-grade mathematics, with a particular emphasis on pattern recognition. Using a one-group experimental design with participants from a federal school in Rawalpindi selected via convenience sampling, their study employed pre- and post-tests over one month. Findings indicated that incorporating unplugged games effectively promoted computational thinking skills, including pattern recognition, among elementary-level mathematics students. Their study concludes that structuring lesson plans with appropriate difficulty levels and content supports students in analysing and interpreting new information, thereby fostering their computational thinking skills, including their ability to recognise and apply patterns.

Yasin and Nusantara (2023) conducted a study to investigate the characteristics of pattern recognition in solving mathematics problems using unplugged computational thinking activities. Their research employed a qualitative descriptive study method and involved three students, one male and two females, selected from a total of 45 participants. Their objective was to observe how pattern recognition functions in problem-solving within the framework of computational thinking. Their findings revealed that the students successfully tackled problems by utilising unplugged computational components such as decomposition, pattern recognition, algorithm, abstraction, and debugging. Key characteristics of pattern recognition identified in the study include understanding the problem through contextual examination, matching questions with past experiences stored in memory, extracting problem components, identifying relationships among extracted components, exploring potential relationships to identify patterns, estimating patterns from various combinations of extracted results, and finally selecting the most suitable pattern based on analysis. Their study concludes that unplugged pattern recognition plays a crucial role in solving mathematical problems within computational thinking, shedding light on how students engage in this process and emphasising its significance in problem-solving. By using unplugged activities, the study highlights the potential for developing essential computational thinking skills without reliance on technology, thereby promoting broader accessibility and engagement.

Voon et al. (2023) conducted a study focused on developing computational thinking (CT) skills among pre-service teachers through experiential learning. Recognising CT as crucial for problem-solving in today's technology-driven society, the research aimed to bridge the gap in understanding how pre-service teachers can integrate CT into their lesson design. Employing hybrid activities that combine plugged and unplugged CT

methods within an experiential learning framework, their study designed a module to help pre-service teachers connect CT concepts with their teaching contexts. Thirty-eight pre-service teachers participated in the twelve-week CT module, which involved integrating, justifying, and reflecting on CT in lesson planning. Results indicated significant improvements in CT competencies among participants, including enhanced pattern recognition and algorithmic thinking skills. These activities proved particularly beneficial for pre-service teachers with limited prior computing knowledge, providing a foundational understanding before integrating CT into programming contexts. Their study underscores the importance of practical CT training modules in preparing pre-service teachers to effectively incorporate computational thinking, including pattern recognition and algorithmic thinking, into their teaching practices.

Aytekin and Topçu (2024) conducted a quasi-experimental study to enhance 6th-grade students' creative problem-solving skills (CPSS) using plugged and unplugged computational thinking activities compared to inquiry-based science activities. Their study involved three groups: one utilising a plugged teaching module, another an unplugged teaching module, and a control group engaged in inquiry-based science activities aligned with the Turkish middle school curriculum. Over 4 weeks, each group received 16 hours of instruction, and data were collected using the Creative Problem Solving Skills Inventory (CPSSI). Results indicated that both the plugged and unplugged teaching modules were significantly more effective than inquiry-based science activities in enhancing CPSS. Furthermore, the unplugged teaching module demonstrated significantly greater success in developing CPSS compared to the inquiry-based activities, highlighting its effectiveness. This study underscores the role of both computational thinking activities in fostering CPSS among middle school

students, with unplugged methods particularly enhancing skills such as pattern recognition, crucial for creative problem-solving.

Tank et al. (2024) conducted a case study focusing on the role of sequencing tasks in developing computational thinking (CT) competencies among young children in K-2 computer science (CS) education. Emphasising the benefits of unplugged CT activities for younger students, the study explored how children aged four to seven demonstrated CT skills through unplugged sequencing tasks using manipulatives. The research identified several CT competencies observed during the tasks, including pattern recognition, algorithms and procedures, problem decomposition, and debugging. Results indicated that children's strategies and use of manipulatives varied in complexity based on their age and developmental levels. Their study suggests that sequencing tasks serve as a developmentally appropriate entry point for young children to engage in various CT competencies. Moreover, these tasks can be seamlessly integrated into early childhood classroom activities, enhancing children's motivation and skills in computational thinking from an early age.

Based on the literature review, unplugged computing activities significantly enhance computational thinking (CT) skills, particularly in problem-solving, algorithmic thinking, and pattern recognition. These activities effectively develop CT components such as decomposition and abstraction. They foster the progression of CT skills across different educational levels and are effective in both STEM and non-STEM subjects.

2.3.7 Abstraction

Abstraction is a critical component of computational thinking, which is a problem-solving activity that involves breaking down complex problems into smaller, more manageable parts, focusing on the most important information, and identifying patterns

and similarities (Ezeamuzie et al. 2022). Abstraction is the process of filtering out irrelevant information and focusing on the essential elements of a problem, allowing for more efficient and accurate problem-solving (Ezeamuzie et al. 2022). Abstraction is used to simplify complex concepts and problems, making them more accessible and easier to understand (Ezeamuzie et al. 2022). For example, students might use abstraction to summarise a novel into a book review, conduct surveys and analyse data, or develop laws and theorems by looking at similar formulas and equations (Ezeamuzie et al. 2022). These examples demonstrate how abstraction can help students identify patterns and relationships and communicate complex ideas more effectively. Abstraction is also a key component of computer science and programming, where it is used to simplify strings of code into different functions, hiding the underlying complexity of a programming language (Ezeamuzie et al. 2022). By abstracting away from specific details, programmers can more easily integrate algorithms and communicate with digital tools, making it easier to solve complex problems.

Arslan et al. (2022) study examines the impact of block-based programming and unplugged coding activities on fifth graders' computational thinking skills, self-efficacy, and academic performance in the "Problem-Solving and Programming" unit of the ITS course. Their research involved 82 students from three public middle schools during the 2020-2021 academic year and utilised an embedded mixed design. Quantitative data were collected via pretest-posttest randomised control groups using the Computational Thinking Self-Efficacy Scale (CTSES), ICT Attitudes Test (IICTATT), and Computational Thinking Performance Test (CTPT). Analysis using Kruskal-Wallis H, paired sample t-tests, and ANCOVA in SPSS showed no significant differences in CTSES scores among the groups. However, students in the unplugged coding group (Experimental 2) outperformed those in the block-based programming

group (Experimental 1) and the control group on IICTATT and CTPT. Qualitative data from semi-structured interviews, analysed in MAXQDA, indicated that the unplugged activities enhance computational thinking by improving problem-solving, pattern recognition, abstract thinking, and algorithm design.

Molina-Ayuso et al. (2022) conducted a study focusing on the introduction of unplugged computational thinking for the training of Spanish primary school teachers in mathematics. Their research presents an empirical investigation into the development of computational thinking knowledge and skills, including abstraction, among pre-service primary teachers. Their study involved integrating unplugged computational thinking practices among 149 students enrolled in primary education university programs as part of their mathematics education training. Employing an experimental design with control and experimental groups, the researchers conducted initial and final measurements using a validated diagnostic tool comprising 30 questions related to computational concepts and their application, referred to as a computational thinking test. Their findings revealed a positive outcome, with the experimental group showing a more significant improvement. Participants' feedback indicated a favourable outlook regarding the relevance of such educational practices in the teaching and learning of mathematics, highlighting their utility and practicality.

Tankiz et al. (2023) conducted a study to examine pre-service teachers' computational thinking (CT) skills and self-efficacy (SE) in teaching CT using unplugged activities. Their study involved 37 pre-service teachers enrolled in an instructional technologies course and employed convergent parallel mixed-methods activities. Quantitatively, a quasi-experimental design with pre-test-post-test measures was used, while thematic analysis was applied for the qualitative component. The integration process had three

stages: first, raising awareness about CT components such as problem decomposition, pattern recognition, algorithm design, and abstraction through unplugged activities; second, developing educational games related to their subject areas using these CT skills; and third, preparing lesson plans teaching CT skills through these developed games. Quantitative findings showed a significant increase in pre-service teachers' CT skills and SE perceptions, with a modest effect on CT skill improvement but a substantial effect on SE perception. Qualitative findings corroborated these results, with pre-service teachers noting that the unplugged activities enhanced their CT skills, SE in teaching, and professional competencies, including technological and pedagogical knowledge.

Yasin and Nusantara (2023) conducted a study to investigate the characteristics of pattern recognition in solving mathematics problems within the realm of computational thinking using unplugged activities. Their research, employing a qualitative descriptive study method, involved three students, one male and two females, selected from a total of 45 participants. Their objective was to observe how pattern recognition functions in problem-solving within the framework of computational thinking. Their findings revealed that the students successfully tackled problems by utilising computational components such as decomposition, pattern recognition, algorithm design, abstraction, and debugging through unplugged activities. Key characteristics of pattern recognition identified in the study include understanding the problem through contextual examination, matching questions with past experiences stored in memory, extracting problem components, identifying relationships among extracted components, exploring potential relationships to identify patterns, estimating patterns from various combinations of extracted results, and finally selecting the most suitable pattern based on analysis. Their study concludes that pattern recognition plays a crucial role in solving

mathematical problems within computational thinking, shedding light on how students engage in this process and emphasising its significance in problem-solving.

Tank et al. (2024) conducted a case study focusing on the role of sequencing tasks in developing computational thinking (CT) competencies among young children in K-2 computer science (CS) education. Emphasising the benefits of unplugged CT activities for younger students, the study explored how children aged four to seven demonstrated CT skills through unplugged sequencing tasks using manipulatives. Their research identified several CT competencies observed during the tasks, including pattern recognition, algorithms and procedures, problem decomposition, and debugging. Results indicated that children's strategies and use of manipulatives varied in complexity based on their age and developmental levels. Their study suggests that sequencing tasks serve as a developmentally appropriate entry point for young children to engage in various CT competencies. Moreover, these tasks can be seamlessly integrated into early childhood classroom activities, enhancing children's motivation and skills in computational thinking from an early age.

Based on the literature review, unplugged coding activities enhance computational thinking skills, especially in problem-solving, pattern recognition, and algorithm design. Pre-service teachers also benefit from these activities, improving their technological and pedagogical skills. Pattern recognition is key in mathematical problem-solving, with students applying computational thinking components effectively. Additionally, sequencing tasks foster foundational computational thinking skills in young children.

2.3.8 Algorithmic Thinking (AT)

Algorithmic thinking (AT) is a way of thinking that involves breaking down a complicated goal into a series of ordered steps using available tools (Stephens & Kadujevich, 2020). It is a critical component in mathematics education, particularly in developing procedural knowledge, which is essential for integrating procedures, especially through designing procedures and algorithms (Kadujevich et al. 2023).

The term 'algorithmic thinking' has been used in mathematics education literature to characterise a way of thinking rather than thinking about algorithms themselves (Stephens & Kadujevich, 2020). It is closely related to computational thinking (CT), which is a broader concept that encompasses many kinds of thinking and activity, such as recursive thinking, abstraction and decomposition, heuristic reasoning, and making trade-offs between time and space (Kadujevich et al. 2023).

AT is particularly relevant in computational settings, where it is used to solve problems, design systematically, and understand human behaviour that draws on concepts fundamental to computer science (Kadujevich et al. 2023). It is a specific, useful construct that is worth trying to engender in students, as it offers broader implicit affordances that are desirable for doing mathematics (Kadujevich et al. 2023). AT is also essential for developing computational thinking, which is increasingly recognised as a critical skill for students to develop in the 21st century (Stephens & Kadujevich, 2020; Kadujevich et al., 2023).

In mathematics education, the main task of technology is to mediate the learning of mathematics in productive ways, including relating procedural and conceptual mathematical knowledge (Stephens & Kadujevich, 2020; Kadujevich et al., 2023). AT may be critical to developing these knowledge types and relating them. For example,

procedural knowledge may be developed through integrating procedures, especially through designing procedures and algorithms for years (Stephens & Kadjevich, 2020; Kadjevich et al., 2023). AT is also closely related to programming and coding, which are increasingly being emphasised in curriculum documents around the world (Stephens & Kadjevich, 2020; Kadjevich et al., 2023).

In the UK, recent educational documents use the terms 'algorithms' and 'algorithmic thinking' instead of 'computational thinking', and algorithms and algorithmic thinking are the preferred terms in the Australian Curriculum: Digital Technologies across all years of schooling years (Stephens & Kadjevich 2020; Kadjevich et al. 2023). In France, algorithmic thinking is taught in mathematics using Python in high school, and there is a clear emphasis on the cross-curricular uses of programming, including the use of programming languages, with specific attention to computer-less programming in the early years (Stephens & Kadjevich, 2020; Kadjevich et al., 2023).

Saxena et al. (2020) conducted an exploratory study focused on cultivating three computational thinking (CT) skills, pattern recognition, sequencing, and algorithm design, through unplugged and plugged activities. The framework, based on Piaget's Theory of Cognitive Development and Asher's Total Physical Response, was developed in two stages. Initially, two sets of unplugged activities using tangible materials were designed to provide concrete experiences of CT and prepare students with the necessary vocabulary for subsequent plugged activities using digital devices. Their study involved 11 kindergarten students in Hong Kong, aged 3 to 6, and six teacher participants. Following 10 hours of CT training, nearly all students demonstrated mastery in pattern recognition and sequencing. However, the youngest students (K1) only partially completed algorithm design tasks, while older students generally met the expected

achievement levels. To improve CT instruction, the study suggests enhancing training on CT language and employing differentiated instruction tailored to pre-schoolers' developmental stages.

Lim and Chen (2021) explore upper primary students' learning experiences with algorithms, a key computational thinking (CT) skill, through unplugged programming activities (UPA). Their study involved 31 students from a rural primary school, who were taught the algorithm concept using UPA materials. Interviews with nine participants revealed four main themes: Good Learning Quality, Much Knowledge, Easy, and Useful, indicating positive learning experiences. Their findings suggest that UPA is effective for teaching algorithms, especially in schools with limited technological infrastructure, and may guide the development of comprehensive UPA modules for teaching CT skills.

Van Borkulo et al. (2021) investigated how to foster algorithmic thinking (AT) and generalisation skills in 12th-grade calculus lessons using the dynamic mathematics software GeoGebra. They designed a six-lesson intervention developed by an interdisciplinary team of researchers and teachers with backgrounds in computer science and mathematics education, aimed at enhancing these skills. The intervention was evaluated in a classroom of 15 students in the Netherlands through the analysis of students' workbooks, files, interviews, and the teacher's logbook. Their findings indicated that both the teacher and students viewed the intervention positively and found their learning and teaching experiences highly satisfactory. Their primary challenges encountered included familiarisation with GeoGebra, syntax issues, and effective use of conditional statements. Their study concludes with a discussion of the

learning and teaching experiences and offers strategies for teachers to address AT and generalisation aspects in mathematics lessons.

Zhan et al. (2022) explored the effects of Unplugged Programming Teaching Aids (UPTA) on computational thinking and classroom interaction among primary school children in southern China. Their study included 48 students aged 6–8, divided into a treatment group utilising UPTA and a control group with standard learning materials. Both groups were evaluated on computational thinking skills, cognitive development (including concrete operations and egocentrism), and classroom interaction. Findings indicated that while children could classify objects based on dual criteria, they often exhibited egocentric thinking and struggled with third-party perspectives. Nonetheless, students in the treatment group scored significantly higher on computational thinking tests and were more actively engaged in classroom interactions than those in the control group. This implies that UPTA effectively enhances children's computational thinking by promoting algorithmic thinking, problem decomposition, and solution strategies, while also fostering collaborative inquiry and communication skills in the classroom.

Kanaki and Kalogiannakis (2022) investigate the relationship between algorithmic thinking skills and age within early childhood STEM education, using unplugged computational thinking activities. Their research aims to contribute to the field of computational thinking assessment, focusing on the first two years of primary school. Employing a quantitative methodology, they utilised an innovative assessment tool specifically designed for the study. Conducted within an environmental study course, their research centred on young learners in the early years of primary education. Their results revealed a significant correlation between algorithmic thinking skills and age, indicating that age is a predictor of computational thinking proficiency in early

childhood settings. Their findings highlight the importance of integrating computational thinking into STEM disciplines to nurture competent citizens capable of addressing complex challenges in the digital era. Their study advocates for continued efforts to incorporate computational thinking into early childhood STEM education, emphasising the need for age-appropriate interventions to enhance algorithmic thinking skills in young learners.

Arslan et al. (2022) study examines the impact of block-based programming and unplugged coding activities on fifth graders' computational thinking skills, self-efficacy, and academic performance in the "Problem-Solving and Programming" unit of the ITS course. Their research involved 82 students from three public middle schools during the 2020-2021 academic year and utilised an embedded mixed design. Quantitative data were collected via pretest-posttest randomised control groups using the Computational Thinking Self-Efficacy Scale (CTSES), ICT Attitudes Test (IICTATT), and Computational Thinking Performance Test (CTPT). Analysis using Kruskal-Wallis H, paired sample t-tests, and ANCOVA in SPSS showed no significant differences in CTSES scores among the groups. However, students in the unplugged coding group (Experimental 2) outperformed those in the block-based programming group (Experimental 1) and the control group on IICTATT and CTPT. Qualitative data from semi-structured interviews, analysed in MAXQDA, indicated that the unplugged activities enhance computational thinking by improving problem-solving, pattern recognition, abstract thinking, and algorithm design.

Kırçali and Özdener's (2023) study investigates the effects of plugged tools (Code.org and Scratch) versus unplugged tools on the development of computational thinking skills, such as problem decomposition, pattern recognition, abstraction, algorithm

design, and algorithmic thinking, among 109 sixth-grade students, with a focus on gender differences. Employing a quasi-experimental design with pre-test and post-test measures over six weeks, the study revealed that the unplugged activities significantly enhanced computational thinking skills, while the plugged tools did not show a similar impact. Although there were no overall significant differences among the groups, male students demonstrated a marked improvement in computational thinking when engaged in the unplugged activities. Their results imply that incorporating unplugged methods could be advantageous for teaching algorithms at the K-12 level, highlighting the need for further research to explore gender-specific educational strategies.

Bacelo and Gómez-Chacón (2023) delve into algorithmic thinking within the framework of computational thinking, emphasising its importance in educational contexts. The research addresses a gap in university-level studies by exploring the connection of algorithmic thinking with mathematical thinking and providing a characterisation to enhance its teaching and evaluation. Using unplugged tasks, the study aims to characterise algorithmic thinking in the Bachelor's Degree in Mathematics, proposing an analytical model with categories that link mathematical and algorithmic domains across semiotic, instrumental, and discursive dimensions. Findings demonstrate the interplay of these dimensions and their predictive value for improving programming performance. Their research contributes novel insights into the roles and interactions among mathematical and computational thinking categories within algorithmic thinking processes.

Based on the literature review, key findings under algorithmic thinking include that unplugged and plugged activities enhance computational thinking, particularly in pattern recognition and sequencing, with younger children requiring more tailored

instruction. Unplugged programming activities are effective for teaching algorithmic concepts, especially in resource-limited settings. Dynamic mathematics software fosters algorithmic thinking, though challenges remain with tool familiarity. Additionally, age correlates with algorithmic thinking proficiency, highlighting the importance of integrating computational thinking into early STEM education.

2.4 Conceptual Framework

Building on the theoretical foundations of constructionism and Experiential Learning Theory, the conceptual framework illustrates the relationships between independent variable, intervening variable and dependent variable. The framework integrates key elements from both theories to provide a holistic understanding of the learning processes and outcomes involved. Figure 1 shows the conceptual framework underpinning the study, illustrating the flow of influence from the independent variable, through the intervening variables, to the dependent variable.

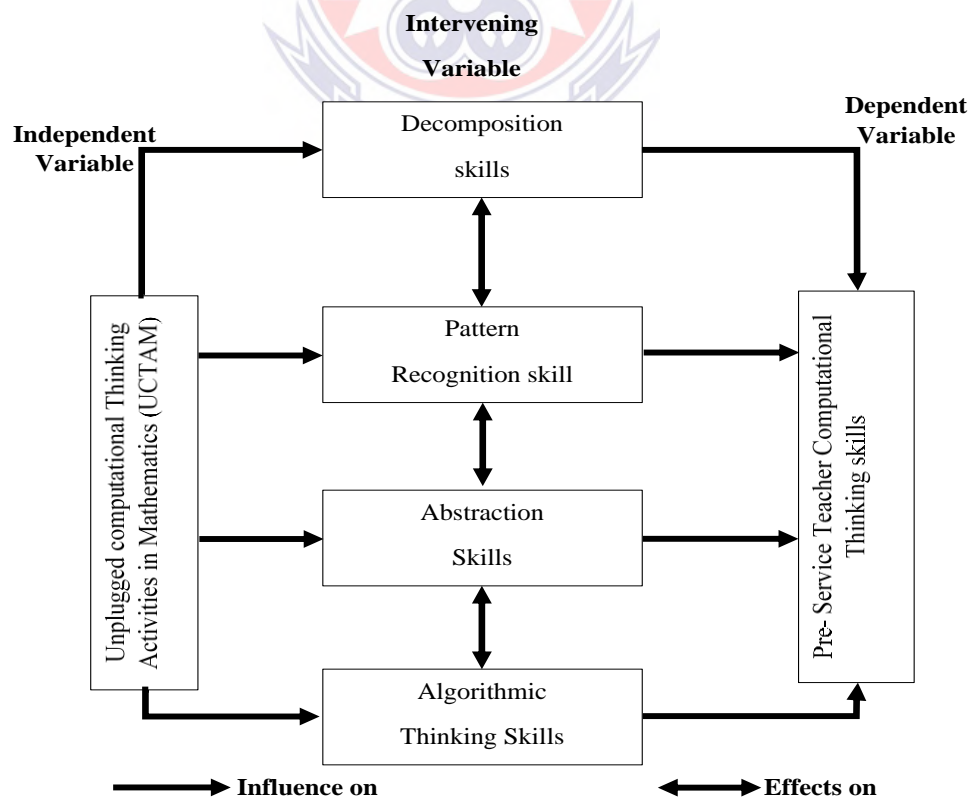


Figure 1: Conceptual Framework of the Study (Developed by the Researcher)

The framework is grounded in Wing's (2006) Computational Thinking Framework, which conceptualises computational thinking as a set of interrelated problem-solving skills. At the foundation of the framework is the independent variable, Unplugged Computational Thinking Activities in Mathematics (UCTAM), non-digital, hands-on instructional activities such as games, puzzles, and physical modelling tasks designed to engage pre-service teachers actively with computational thinking concepts within mathematics contexts. These activities provide opportunities for learners to develop computational thinking skills in tangible ways, without the use of digital technologies, thereby fostering deeper conceptual understanding and enhancing instructional creativity.

The conceptual framework demonstrates that UCTAM has a direct influence on four core computational thinking constructs, which function as intervening or mediating variables within the model. These constructs include decomposition skills, pattern recognition skills, abstraction skills, and algorithmic thinking skills. Decomposition skills enable pre-service teachers to break down complex mathematical problems into smaller, manageable components, facilitating clearer understanding and strategic problem solving. Pattern recognition skills allow them to identify structures, trends, and regularities within mathematical tasks, supporting generalisation and efficient solution development. Abstraction skills help them filter out irrelevant details to focus on essential features of problems, thus simplifying and clarifying the problem-solving process. Algorithmic thinking skills equip them to formulate logical, stepwise procedures or algorithms necessary for solving mathematical problems systematically and effectively.

The framework further shows that the development of these four constructs has effects on the dependent variable, Pre-Service Teachers' Computational Thinking Skills. Specifically, as pre-service teachers enhance their decomposition, pattern recognition, abstraction, and algorithmic thinking skills, their overall computational thinking competence is improved. This improvement strengthens their ability to analyse mathematical problems critically, design appropriate solution strategies, and integrate computational thinking concepts into their instructional practices with confidence.

2.5 Empirical Review

The section presents a review of empirical studies that have explored the use of unplugged CT activities in mathematics education. The review highlights key findings on the effectiveness of unplugged CT activities in enhancing computational thinking skills, improving problem-solving abilities, and fostering critical thinking. It also examines the challenges identified in implementing such activities and their relevance to the teaching and learning of mathematics.

2.5.1 Computational Thinking in the Ghanaian Mathematics Classroom

This review explores the integration of Computational Thinking (CT) in the Ghanaian mathematics classroom, focusing on its potential to enhance mathematical understanding and problem-solving skills. The review aimed to highlight both the benefits and challenges of CT integration in Ghanaian classrooms.

Appah et al. (2020) aimed to enhance algebraic thinking among primary pupils and stimulate their interest in mathematics. Employing pre-intervention and post-intervention assessments alongside questionnaires, the researchers evaluated the algebraic thinking skills of fifteen (15) students, comparing them with a control group of seventy-eight peers. Their findings revealed subpar performance among the pupils,

but significant improvement was observed following the integration of Active Learning strategies focused on Cognitive Reasoning. Despite initially displaying limited developmental thinking in algebraic problem-solving and harbouring reservations about mathematics, the students showcased notable enhancement in their algebraic thinking abilities. Their study underscores the efficacy of Practical Active Learning activities centred on Cognitive Reasoning to cultivate algebraic thinking among primary pupils. Additionally, it advocates for encouraging students to tackle word problems using their conceptual understanding, integrating real-life scenarios into problem-solving activities, and providing consistent teacher encouragement to foster a sustained interest in mathematics.

Marful et al. (2022) delve into the exploration of design thinking as a potent tool for architectural pedagogy, with a specific emphasis on its challenges and benefits within the educational landscape of Ghana. Through an exploratory study, the researchers seek to delineate existing teaching and learning paradigms in architectural education and confront obstacles hindering students' adoption of design thinking activities. Their study endeavours to cultivate awareness among Ghanaian students regarding the potential of design thinking to catalyse creativity and innovation in architectural practice. Noting the limited application of design thinking in architectural pedagogy, as evidenced by the reviewed literature, the research advocates for further inquiry into the integration of design thinking methodologies within architectural design education. Adopting a pragmatic philosophical stance, their study prioritises problem-solving and practical application, eschewing a singular focus on methods and instead embracing diverse activities to comprehensively understand the research task. Integrating computational thinking principles into the pedagogical framework may further augment

students' problem-solving abilities and expand their capacity for activities with architectural design challenges, with computational efficiency and innovation.

Agyei et al. (2023) embarked on a study to scrutinise the incorporation of digital technologies by Senior High School mathematics teachers in Ghana, with a focus on exploring the potential for computational thinking and transforming pedagogical practices through technology integration. Employing an explanatory sequential mixed methods design, the research amalgamated data from 202 mathematics teachers via a blend of quantitative (questionnaire) and qualitative (classroom observation and semi-structured interviews) activities. Guided by the SAMR model as a theoretical framework, their investigation unveiled a prevalence of low levels of technology integration in mathematics instruction, predominantly confined to the substitution and augmentation stages, with scant evidence of pedagogical practices undergoing modification or redefinition. Notably, calculators emerged as the most commonly utilised digital tool, primarily for tasks akin to substitution and augmentation. Mathematics instructors predominantly employed technology for routine activities such as lesson preparation, computational tasks during class sessions, and validating mathematical solutions, exhibiting minimal indications of transformative practices. Their study underscores the imperative of furnishing training and support mechanisms to bolster teachers' technological acumen, highlighting the potential for transformative teaching strategies that foster students' computational thinking skills and deepen their comprehension of mathematical concepts.

Amenyo and Kpo (2023) initiated the TechViwoEDU Project with the ambitious goal of revolutionising mathematics education in rural villages worldwide by integrating computational thinking alongside programmable educational drones, robots, and AI.

This ground-breaking endeavour is founded on the premise that providing access to these advanced yet affordable technologies can not only enrich the learning experiences of rural children but also equip them with indispensable skills for the future job market. Central to the project's activities is the utilisation of low-cost technologies, such as programmable drones and coding robots, which play a pivotal role in facilitating skill development in areas including problem-solving, critical thinking, and computational thinking. Drones are employed as versatile educational tools, engaging students in various mathematical concepts and fostering dynamic, active learning environments. Acknowledging the challenges associated with disseminating information effectively, the project endeavours to develop user-friendly interfaces to address this concern. With its inaugural pilot program launched in Tsrukpe, Ghana, the TechViwoEDU Project aims to bridge the educational gap in rural communities, empowering students with essential skills for success in the 21st-century workforce. Ultimately, this pioneering initiative represents a paradigm shift in educational practices, striving to introduce innovative educational activities globally while promoting equitable access to quality education and empowering students to thrive in an increasingly dynamic global landscape enriched by computational thinking principles.

Fokuo et al. (2023) conducted a systematic review focusing on the utilisation of visualisation tools in teaching mathematics in colleges of education, with a particular emphasis on integrating computational thinking principles. This comprehensive review addresses the burgeoning interest in incorporating visualisation tools into higher education mathematics instruction, particularly within college settings. Through the analysis of 25 published papers, the study aims to provide a comprehensive overview of the efficacy of visualisation tools, their impact on students' learning outcomes, and the challenges associated with their integration. Employing rigorous methodology,

including meticulous search strategies, stringent article selection criteria, and thorough quality assessment procedures, the review categorises visualisation tools into various types, encompassing digital simulations, interactive software, and physical manipulatives. It assesses their effectiveness in enhancing students' understanding of mathematical concepts and problem-solving skills, with a specific focus on computational thinking development. Key findings underscore the positive influence of visualisation tools in fostering active engagement, conceptual comprehension, and motivation among college students, thereby facilitating the integration of computational thinking into mathematics education. Furthermore, the review identifies potential challenges, including technological barriers, instructional strategies, and differing learning preferences, which necessitate consideration by teachers and curriculum designers when integrating visualisation tools into the mathematics classroom with an emphasis on computational thinking proficiency.

Based on the literature review, integrating computational thinking (CT) into mathematics education significantly enhances problem-solving, critical thinking, and engagement. The use of digital tools, robots, and active learning strategies fosters deeper understanding and motivation among students. However, challenges such as limited technology integration and insufficient teacher training were noted. Studies emphasise the need for comprehensive teacher support and resources to effectively incorporate CT. Overall, CT integration shows strong potential to improve mathematical learning outcomes.

2.5.2 Plugged CT Activities in Mathematics Education

The review explores the integration of Plugged Computational Thinking (CT) activities into mathematics education. The review aims to provide insights into how integrating

plugged CT activities improves pre-service teachers' ability to teach mathematical concepts effectively.

Ye et al. (2023) conducted a systematic review focusing on the integration of Computational Thinking (CT) in K-12 STEM education. Their objective was to examine CT-based instruction in STEM subjects and its influence on student learning. The study utilised the Web of Science database to identify articles published between 2006 and 2021, resulting in the selection of 24 articles for analysis. These articles offered insights into CT-based instruction in STEM subjects and its effects on student learning across various educational levels and contexts. Their analysis categorised the articles based on factors such as educational levels, contexts, programming tools used, learning outcomes in CT and STEM, and the relationship between CT and STEM learning. Their results emphasised the effectiveness of geometrized programming and student-centred instructional activities in enhancing learning outcomes in both CT and STEM. CT-based STEM learning involves an interactive and cyclical process. Their findings contribute valuable insights into the impact of CT-based instruction on student learning in K-12 settings, furthering understanding of the mechanisms and outcomes associated with integrating CT into STEM education.

Mumcu et al. (2023) conducted a study centred on integrating Computational Thinking (CT) into mathematics education by utilising an unplugged computer science (CS) activity. Their objective was to explore CT's application in mathematics education, analyse classroom strategies, and gather feedback from students and pre-service teachers regarding the unplugged CS activity. The researchers devised an unplugged CS activity to merge CT elements, computer science principles, and mathematics educational objectives. Twelve (12) pre-service teachers underwent training to integrate

the unplugged CS activity in actual classroom settings. Subsequently, these teachers facilitated the activity with 80 middle school students across four classes. The activity's design encompassed diverse CT components, including data collection, analysis, decomposition, pattern recognition, algorithmic design, testing, and debugging. Feedback from the middle school students revealed their enjoyment of the activity and its effectiveness as a learning experience in mathematics. Nonetheless, they indicated a need for assistance in connecting the activity with computer science concepts. Pre-service teachers reported difficulties in managing the classroom during the activity, underscoring the importance of integrating classroom management training into teacher education programs. Their study advocates for the development of courses tailored for pre-service teachers, covering classroom management, CS activity design, and integration. These courses should be grounded in both theoretical frameworks and practical applications within mathematics.

Yilmaz & Yilmaz (2023) conducted a study to examine the impact of integrating programming education utilising ChatGPT on students' computational thinking skills, programming self-efficacy, and motivation toward the lesson. Their research involved 45 undergraduate students enrolled in a university-level programming course and followed an experimental design with pretest-posttest control groups. Participants were randomly assigned to either the experimental group ($n = 21$), where students utilised ChatGPT during weekly programming practices, or the control group ($n = 24$), where this tool was not employed. Data collection utilised the computational thinking scale, computer programming self-efficacy scale, and learning motivation in computer programming courses scale. Their results indicated that students in the experimental group exhibited significantly higher levels of computational thinking skills, programming self-efficacy, and motivation compared to the control group. They

suggest the potential utilisation of leveraging AI technologies like ChatGPT in programming education. The study also highlighted strategies for effectively integrating AI support in lessons and provided suggestions for researchers and teachers in this domain.

Kırçali & Özdener (2023) conducted a study to investigate the impact of plugged and unplugged programming tools on algorithm teaching within the STEM domain at the K-12 level, while also examining potential gender differences. Their research employed a control group pre-test–post-test quasi-experimental design, involving 109 6th-grade students from a secondary school. Random selection was used to choose three out of four branches in the school, with experiment and control groups determined through random assignment. Over six weeks, experiment group 1 utilised Code.org, experiment group 2 employed unplugged tools, and the control group was instructed to use Scratch. Data was collected using the "Computational Thinking Levels Scale" as both pre- and post-tests. Their findings revealed that students taught with unplugged activities demonstrated positive advancements in computational thinking skills, whereas no significant improvements were observed in the other groups. Furthermore, there were no notable differences in computational thinking skills when comparing the group overall. Gender was not identified as a significant factor influencing the results, although male students exhibited slight advantages when engaged in the unplugged activities.

Dahshan & Galanti (2024) conducted a qualitative exploratory study aimed at investigating the collaboration between teachers in a graduate mathematics education program. Their focus was on exploring and critiquing a series of integrated mathematics and Computational Thinking (CT) block-based programming activities designed to

enhance conceptual understanding of place value. Thirteen (13) in-service elementary teachers enrolled in an online graduate CT course for teachers participated in the study. They engaged with the activities as learners and drew upon their experiences as classroom teachers to provide feedback for program redesign. The researchers analysed course transcripts, collaborative problem-solving slides, and individual teacher reflections using deductive pattern coding and inductive holistic coding techniques. Their analysis revealed how teachers established connections between their existing mathematical knowledge related to teaching place value and their evolving understanding of CT concepts. Their study highlighted how teachers integrated CT concepts into their pedagogical practices and provided valuable feedback for the design of professional development programs aimed at integrating CT and mathematics in elementary education. The findings have implications for the design of professional development initiatives for elementary teachers, emphasising the importance of integrating CT concepts into mathematics instruction and providing support for teachers to effectively incorporate these concepts into their teaching practices.

Based on the literature review, the integration of plugged Computational Thinking (CT) into mathematics education has shown positive impacts on student learning outcomes. Plugged CT activities, such as programming and using software tools, enhance key skills like pattern recognition, decomposition, and abstraction. These activities improve computational thinking, programming self-efficacy, and motivation among students. Additionally, technology-based CT programs foster critical thinking and positive attitudes toward technology. Overall, plugged-in CT activities are effective in improving computational thinking skills and teaching complex mathematical concepts like algorithms.

2.5.3 Unplugged CT Activities in Mathematics Education

The review explores the integration of unplugged CT activities into mathematics education. It examines how unplugged activities foster key computational thinking skills such as pattern recognition, decomposition, and abstraction in pre-service teachers. The review aims to provide insights into how integrating unplugged activities enhances pre-service teachers' ability to teach mathematical concepts effectively.

Sun et al. (2021) conducted an 8-week quasi-experimental study with 93 7th-grade students to examine the effectiveness of unplugged programming activities in enhancing computational thinking (CT) skills. Their study included 62 students in two experimental groups who participated in the unplugged activities and 31 students in a control group who did not. Their results demonstrated that the unplugged programming activities significantly improved CT skills, outperforming the control group. While students' mathematical performance and prior programming experience influenced their overall CT skills, these factors did not affect the outcomes of the unplugged programming activities, indicating that all students, regardless of their academic background, benefited from the intervention. Their findings suggest that unplugged programming activities are an effective, inclusive activity for developing CT skills in junior high school students, with important implications for educational practices.

Chan et al. (2021) conducted a study to explore the impact of computational thinking (CT) activities focused on number patterns on the learning performance of secondary students in Singapore. Their research involved 106 Secondary One students (aged 13 years) from a secondary school, using a quasi-experimental non-equivalent groups design. Seventy students were assigned to the experimental group, which received CT-infused activities both on- and off-computer, while 36 students formed the control group

with no intervention. Both groups underwent pretest and posttest assessments, analysed using the Rasch model. Their study found that overall, the experimental group's performance on the post-test was similar to that of the control group, failing to support the hypothesis that integrating the CT activities leads to improved mathematics learning across the board. However, significant individual improvements were noted among students in the experimental group, contrasting with minimal improvements in the control group. Their findings contribute empirical evidence and practical insights into integrating CT practices effectively into mathematics education.

Sim et al. (2021) conducted an investigation aimed at developing an unplugged computational thinking (CT) activities framework for novice programmers. Their study assessed the effectiveness and appropriateness of various unplugged CT activities as part of the framework development process. Two iterations were carried out to validate the suitability of these activities, which were further verified with a group of secondary school teachers. Their findings highlighted the effectiveness of unplugged activities in facilitating programming skill development among students. Moving forward, their research intends to identify additional components necessary for the framework of the unplugged CT activities tailored for novice programmers.

Polat and Yilmaz (2022) conducted a study comparing the effects of unplugged and plugged-in activities on academic achievement and computational thinking (CT) skills of sixth-grade students. Utilising mixed-methods research, their study employed a quasi-experimental design with two groups for the quantitative phase and interviews with 12 students for the qualitative phase. The participants included 84 sixth-grade students aged 10 to 11. Unplugged activities were based on the proposed national curriculum, while plugged-in activities utilised basic programming web platforms.

Their results indicated significant differences favouring unplugged activities in academic achievement but not in CT skills. However, the development of CT skills contributed to the academic achievement of the unplugged group. Qualitative findings revealed that the plugged-in group perceived their activities as entertaining but not strictly educational, while the unplugged group viewed their activities as both educational and enjoyable. CT explained a significant portion of the variance in academic achievement, emphasising its importance in basic programming. Their study suggests that students can enhance academic achievement and maintain CT acquisition across unplugged and plugged-in activities, contributing to the understanding of the positive impact of unplugged activities on teaching CT and programming fundamentals. Merino-Armero et al. (2022) conducted a quasi-experimental study on the impact of unplugged activities in cross-curricular teaching, focusing on computational thinking (CT) and learning outcomes among sixth-grade students in Social Sciences. In this study, 14 students participated in an unplugged intervention where they programmed an imaginary robot on paper, while 31 control group students continued with regular classes. Their results demonstrated a significant increase in CT skills ($p < 0.001$) with a large effect size ($d = 1.305$) for the intervention group, without any decline in academic achievement. Their study indicates that CT can be effectively integrated into non-STEM subjects, allowing students to develop CT skills while maintaining their academic performance in regular curricular content.

Vieira et al. (2023) examined the impact of combining unplugged and plugged activities on students' computational thinking (CT) skills through a quasi-experimental study. Teachers integrated lesson plans incorporating unplugged activities to scaffold learning and plugged activities using the Micro device, following a use-modify-create progression. Their study compared the CT skills of program participants with a control

group and found a significant positive effect of the learning activities on students' CT knowledge and skills. This positive effect remained consistent even after accounting for school context and student gender. Conducted in a developing country, this large-scale study highlights the effectiveness of blended activities in CT education, providing a valuable model for similar educational contexts.

Chen et al. (2023) conducted a systematic review and meta-analysis to assess the impact of unplugged activities on fostering computational thinking (CT) skills in K–12 education. Their review encompassed 49 studies conducted between 2006 and 2022, predominantly in computer science and STEM education (81.64%), with board and card games being the most commonly employed unplugged activities. CT diagnostic tools were frequently used (36.37%) for assessment. The meta-analysis of 13 studies, comprising 16 effect sizes, revealed a substantial overall effect size (Hedges' $g = 1.028$, 95% CI [0.641, 1.415], $p < 0.001$) for the effectiveness of unplugged activities in enhancing students' CT skills. Analysis of moderator variables such as grade level, class size, intervention duration, and learning tools indicated that the unplugged activities hold promise as an instructional strategy for CT skill development. Their findings underscore the efficacy of unplugged pedagogy in K–12 education and suggest implications for policy, practice, and future research in integrating CT education.

Piedade and Dorotea (2023) conducted a study to evaluate the impact of Scratch-based activities on the computational thinking (CT) skills of 4th-grade students over one school year. Their research focused on comparing the outcomes of students engaged in the Scratch activities with those who did not participate. Their study included 189 students from two school clusters, divided into an experimental group and a control group. Results indicated significant differences between the groups, with students in

the experimental group, who engaged in the Scratch activities, achieving higher scores compared to the control group. Their findings underscore the effectiveness of the Scratch-based activities in enhancing CT skills and conceptual understanding among elementary school students.

Agbo et al. (2024) conducted a study to explore how unplugged activities facilitate novice students' understanding of computational thinking (CT) and unravel the characteristics of their CT competency. Their research employed mixed-method activities and a quasi-experimental design involving 210 students enrolled in an introductory programming course at a university in Nigeria. Their study found a significant increase in students' familiarity with CT concepts following the intervention, as indicated by paired-sample t-tests. Additionally, Latent Dirichlet Allocation (LDA) was utilised for topic modelling of students' solution descriptions, revealing that 27.62% of solutions incorporated CT concepts, and 56.90% achieved optimal scores in problem-solving tasks. Importantly, 72.41% of students who applied CT concepts like problem abstraction and decomposition correctly solved the puzzles. Their findings underscore the effectiveness of the CT unplugged activities in enhancing students' CT competency. The study concludes with recommendations for computer science educators and outlines future research directions in this area.

Zhang et al. (2024) conducted a meta-analysis to investigate the effects of unplugged programming activities on computational thinking (CT) among K-9 students. Drawing from 15 experimental and quasi-experimental studies conducted between 2006 and 2023, their study quantitatively analysed the impact of unplugged programming activities on CT development, considering variables such as grade level, gender, experimental duration, research discipline, and types of unplugged activities. Their

findings indicate a positive effect of the unplugged programming activities on K-9 students' CT skills (Hedges' $g = 0.631$, 95% CI [0.463, 0.799], $p < 0.001$). The effectiveness of these activities varied based on factors like grade level, duration of learning, subjects studied, and the specific types of unplugged activities employed. Based on these conclusions, the study suggests several recommendations, including focusing on CT development in middle school students, optimising the timing of the unplugged activities to prevent plateau effects, integrating the unplugged activities across disciplines, and promoting collaborative and storytelling activities in unplugged programming education. These insights contribute to understanding how best to integrate and enhance CT skills through unplugged programming activities in K-9 education settings.

Liu and Hu (2024) conducted a six-week quasi-experimental study in a rural primary school in Guizhou, China, focusing on the impact of unplugged programming activities on students' computational thinking (CT) skills and resilience. Their study involved 43 students in the experimental group who participated in the unplugged activities, while 45 students in the control group did not engage in any programming activities. Results indicated significant improvements in CT skills and resilience among the experimental group post-intervention, contrasting with the control group. Gender differences were explored, revealing similar growth in CT skills and resilience across all students. Their study highlighted resilience as a critical factor in enhancing CT skills. Qualitative interviews complemented these quantitative findings, providing deeper insights. Their research offers valuable implications for educators aiming to enhance rural education and integrate CT education effectively into primary school curricula.

Based on the literature review, unplugged CT activities significantly enhance computational thinking (CT) skills in students. Unplugged CT activities have been shown to improve students' CT abilities across various grade levels. Additionally, unplugged CT activities contribute to academic achievement and problem-solving skills.

2.5.4 Unplugged CT Activities on the Development of CT Skills

The review explores unplugged CT activities for pre-service teachers on CT skills. It examines how unplugged CT activities enhance their ability to develop key skills such as algorithmic thinking, pattern recognition, decomposition, and abstraction. The review aims to provide insights into how unplugged CT activities influence pre-service teachers' capacity to apply CT skills effectively in teaching and understanding mathematics.

Delal and Oner (2020) investigated the impact of unplugged computing activities, based on the Bebras challenge, on developing computational thinking (CT) skills among 6th-grade students. Their study focused on CT skills commonly identified in the literature, including problem-solving, algorithmic thinking, pattern recognition, abstraction, and decomposition. Tasks were designed with varying difficulty levels to encompass these foundational CT processes. Results from pre-test and post-test evaluations using Bebras tasks showed significant improvement in students' CT skills after engaging in unplugged activities. Importantly, their study found no significant differences in CT skill development based on students' gender, indicating the inclusive nature of the unplugged computing activities in fostering CT skills among middle school students.

Saxena et al. (2020) conducted an exploratory study focused on cultivating three computational thinking (CT) skills, pattern recognition, sequencing, and algorithm

design, through unplugged and plugged activities. The framework, based on Piaget's Theory of Cognitive Development and Asher's Total Physical Response, was developed in two stages. Initially, two sets of unplugged activities using tangible materials were designed to provide concrete experiences of CT and prepare students with the necessary vocabulary for subsequent plugged activities using digital devices. Their study involved 11 kindergarten students in Hong Kong, aged 3 to 6, and six teacher participants. Following 10 hours of CT training, nearly all students demonstrated mastery in pattern recognition and sequencing. However, the youngest students (K1) only partially completed algorithm design tasks, while older students generally met the expected achievement levels. To improve CT instruction, the study suggests enhancing training on CT language and employing differentiated instruction tailored to preschool developmental stages.

Threekunrapam and Yasri (2020) conducted a qualitative study focusing on how secondary school students develop computational thinking (CT) skills through unplugged coding activities, utilising the 3S activities for self-directed learning. Their research aimed to fill gaps in understanding CT skill progression during unplugged coding tasks, which employed flowcharts to teach essential computer science concepts across five missions. Data collected from 120 students through video recordings underwent thematic analysis, revealing three distinct stages of CT development: initial, partial, and full proficiency. These stages reflected students' varying abilities to apply computer science concepts effectively in completing tasks. Their study also introduced the 3S self-directed learning model, comprising self-checking and self-debugging in pairs, supplemented with scaffolding, to support CT skill advancement. These activities support integrating structured unplugged coding activities with the 3S model to foster comprehensive CT skill development among high school learners.

Zhan et al. (2022) investigated the impact of Unplugged Programming Teaching Aids (UPTA) on children's computational thinking and classroom interaction in a primary school in southern China. Their study involved 48 students aged 6–8, divided into a treatment group with UPTA and a control group using standard learning materials without UPTA. Both groups were assessed on computational thinking ability, cognitive development (including concrete operations and ego-centricity), and in-classroom interaction. Results showed that while children demonstrated the ability to classify objects based on dual criteria, they tended towards ego-centric thinking and faced challenges in adopting a third-party perspective. However, students in the treatment group scored significantly higher in computational thinking tests and exhibited more active engagement in classroom interactions compared to the control group. Their finding suggests that UPTA effectively promotes children's computational thinking by encouraging problem decomposition and solution strategies, fostering collaborative inquiry and communication skills in the classroom.

Kastner-Hauler et al. (2022) conducted a study to investigate the combined impact of block-based programming and physical computing on computational thinking (CT) skills among primary students. Their study aimed to design teaching units for third and fourth-grade students (aged 8-10). These units integrated an Open Educational Resource (OER) textbook with Physical Computing using the micro:bit device. Integrated over three weeks in two classes, the learning environment included teacher training, pre-and post-test assessments, and data analysis to assess the influence on students' CT skills. Their results suggested that the combination of block-based programming and physical computing devices holds the potential for enhancing CT skills in lower school grades, while also facilitating easy access to CT in classroom settings.

Arslan et al. (2022) study explores the effects of block-based programming and unplugged coding activities on fifth graders' computational thinking skills, self-efficacy, and academic performance in the "Problem-Solving and Programming" unit of the ITS course. Conducted with 82 students from three public middle schools during 2020-2021, the study used an embedded mixed design. Quantitative data gathered via pretest-post-test randomised control groups using the CTSES, IICTATT, and CTPT were analysed with Kruskal-Wallis H, paired sample t-test, and ANCOVA tests in SPSS, showing no significant differences in CTSES scores among groups. However, students in unplugged coding (Experimental 2) outperformed those in block-based programming (Experimental 1) and control groups on IICTATT and CTPT. Qualitative data from semi-structured interviews, analysed in MAXQDA, revealed that the unplugged activities enhance computational thinking by improving problem-solving, pattern recognition, abstract thinking, and algorithm design.

Kirçali and Özdener's (2023) study examines the impact of plugged (Code.org and Scratch) versus unplugged tools on developing computational thinking skills, such as problem decomposition, pattern recognition, abstraction, and algorithm design, among 109 sixth-grade students, also considering gender differences. Using a quasi-experimental design with pre-test and post-test measures over six weeks, the study found that the unplugged activities significantly improved computational thinking skills, while plugged tools did not. Despite no overall significant differences among groups, male students showed a notable advantage in computational thinking when engaged in unplugged activities. Their findings suggest that incorporating unplugged methods may be beneficial in teaching algorithms at the K-12 level, though further research is needed to explore gender-specific educational strategies.

Piedade and Dorotea (2023) investigated the impact of Scratch-based activities on computational thinking skills among 4th-grade students over one school year. The study included 189 students from two school clusters, with participants divided into experimental and control groups. Utilising the Beginners Computational Thinking Test by Zapata-Cáceres et al. (2020), significant differences were found between groups, showing higher scores for students engaged in the Scratch activities compared to those who did not participate. The scratch activities enhanced essential computational thinking skills such as problem-solving through the decomposition of complex tasks, algorithmic thinking by creating step-by-step procedures, logical reasoning in predicting outcomes and debugging errors, creativity through designing interactive projects, and pattern recognition in programming constructs. Their findings underscore the effectiveness of Scratch as a tool to foster foundational computational skills crucial for academic success and preparing students for future challenges in a technology-driven world.

Voon et al. (2023) investigate the enhancement of computational thinking (CT) competencies among pre-service teachers using an experiential learning framework. Acknowledging CT as crucial for problem-solving in a technology-driven society, their research addresses gaps in preparing pre-service teachers to incorporate CT into their lesson plans. Over 12 weeks, the researchers integrated a module that blends both plugged and unplugged CT methods, aiming to help pre-service teachers bridge CT concepts with their teaching contexts. Thirty-eight participants engaged in the module, demonstrating improvements in CT competencies through activities that involved integration, justification, and reflection on CT within lesson designs. Their study underscores the value of practical CT training modules that feature unplugged activities, especially beneficial for pre-service teachers lacking prior computing

experience, before advancing to programming-oriented contexts. This activity highlights the role of experiential learning in cultivating effective CT integration skills among future educators.

Based on the literature review, unplugged CT activities have been found to significantly enhance core computational thinking skills such as decomposition, pattern recognition, and algorithmic thinking. These activities foster increased student engagement and promote inclusivity. Unplugged CT activities also support self-directed learning, critical thinking, and cognitive skill progression. Additionally, pre-service teachers benefit from experiential learning modules, improving their ability to integrate unplugged CT activities into their teaching practices.

2.5.5 Unplugged CT Activities on Conceptual Understanding in Mathematics

The review explores the effect of unplugged CT activities on pre-service teachers' understanding of mathematics. It examines how unplugged CT activities enhance their grasp of mathematical concepts by fostering skills like pattern recognition, decomposition, and abstraction. The review aims to provide insights into how unplugged CT activities influence pre-service teachers' ability to apply these concepts effectively in teaching mathematics.

Kannadass et al. (2023) investigate the relationship between computational and critical thinking and their impact on the modelling competency of pre-service teachers using unplugged computational thinking activities. Their research aims to explore how computational thinking and critical thinking intertwine with mathematical modelling proficiency. Employing a correlational quantitative research design, their study involved 140 pre-service teachers from the Institute of Teacher Education in Penang and Ipoh, utilising random cluster sampling. Their results indicate a strong inclination

towards computational and critical thinking among pre-service teachers but reveal limited proficiency in mathematical modelling. Notably, a significant correlation between computational thinking, critical thinking, and modelling proficiency emerged. Their findings highlight that unplugged activities for computational and critical thinking enhance prospective mathematics teachers' modelling skills, emphasising their interconnectedness in fostering mathematical competence. By integrating unplugged methods, the study underscores the potential for developing essential thinking skills without reliance on technology, thereby promoting broader accessibility and engagement.

Mumcu et al. (2023) conducted a study centred on integrating Computational Thinking (CT) into mathematics education by utilising an unplugged computer science (CS) activity. Their objective was to explore CT's application in mathematics education, analyse classroom strategies, and gather feedback from students and pre-service teachers regarding the unplugged CS activity. The researchers devised an unplugged CS activity to merge CT elements, computer science principles, and mathematics educational objectives. Twelve (12) pre-service teachers underwent training to integrate the unplugged CS activity in actual classroom settings. Subsequently, these teachers facilitated the activity with 80 middle school students across four classes. The activity's design encompassed diverse CT components, including data collection, analysis, decomposition, pattern recognition, algorithmic design, testing, and debugging. Feedback from the middle school students revealed their enjoyment of the activity and its effectiveness as a learning experience in mathematics. Nonetheless, they indicated a need for assistance in connecting the activity with computer science concepts. Pre-service teachers reported difficulties in managing the classroom during the activity, underscoring the importance of integrating classroom management training into teacher

education programs. Their study advocates for the development of courses tailored for pre-service teachers, covering classroom management, CS activity design, and integration. These courses should be grounded in both theoretical frameworks and practical applications within mathematics.

Dahshan & Galanti (2024) conducted a qualitative exploratory study aimed at investigating the collaboration between teachers in a graduate mathematics education program. Their focus was on exploring and critiquing a series of integrated mathematics and Computational Thinking (CT) block-based programming activities designed to enhance conceptual understanding of place value. Thirteen (13) in-service elementary teachers enrolled in an online graduate CT course for teachers participated in the study. They engaged with the activities as learners and drew upon their experiences as classroom teachers to provide feedback for program redesign. The researchers analysed course transcripts, collaborative problem-solving slides, and individual teacher reflections using deductive pattern coding and inductive holistic coding techniques. Their analysis revealed how teachers established connections between their existing mathematical knowledge related to teaching place value and their evolving understanding of CT concepts. Their study highlighted how teachers integrated CT concepts into their pedagogical practices and provided valuable feedback for the design of professional development programs aimed at integrating CT and mathematics in elementary education. The findings have implications for the design of professional development initiatives for elementary teachers, emphasising the importance of integrating CT concepts into mathematics instruction and providing support for teachers to effectively incorporate these concepts into their teaching practices.

Angraini et al. (2024) assess students' proficiency in computational thinking within the Mathematics Education program using unplugged computational thinking activities, focusing on the constructivist learning theory. Their study aims to explore the impact of constructivist activities on enhancing students' mathematical computational thinking skills. Employing qualitative descriptive research, they investigate the learning process of students in acquiring computational understanding and applying computational principles in mathematics education. Conducted in the Department of Mathematics Education, the research centres on students enrolled in the Algebraic Structure course during the academic year 2023/2024, with 34 students included as subjects. The findings highlight the effectiveness of the constructivist learning paradigm in improving the mathematical computational thinking abilities of Mathematics Education students. The study reveals that students' prior mathematical knowledge influences their computational thinking proficiency, particularly within the constructivist learning framework. By using unplugged activities, the research underscores the potential for developing essential computational thinking skills without reliance on technology, thus promoting broader accessibility and engagement in mathematics education.

The literature review highlights that unplugged CT activities enhance computational and critical thinking skills, improving modelling proficiency among pre-service teachers without the need for technology. The unplugged CT activities engage pre-service teachers and students in mathematical learning, deepening their understanding of mathematical concepts. Additionally, constructivist approaches to unplugged activities positively impact pre-service teachers' computational thinking abilities, with prior mathematical knowledge playing a crucial role in the learning process.

2.5.6 Perceptions of Students on Unplugged CT Activities in Learning Mathematics

The review explores students' perceptions of unplugged CT activities in learning mathematics. It examines how students view the effectiveness and practicality of unplugged CT activities and their effects on their understanding of mathematical concepts. The review aims to provide insights into how unplugged activities influence the learning experience in mathematics education.

Love et al. (2022) examined changes in K-2 teachers' beliefs about integrating computational thinking (CT) to teach literacy and mathematics concepts following a professional development (PD) experience. Their study involved 45 teachers from 30 school districts who participated in online sessions focused on integrating the Sphero Indi into their classrooms. Using the Teacher Beliefs about Coding and Computational Thinking (TBaCCT) instrument, their study found significant increases in teachers' beliefs related to CT value, CT self-efficacy, coding self-efficacy, and teaching efficacy, with moderate to large effect sizes. Supplementary questions indicated a moderate increase in beliefs regarding CT's potential to enhance student engagement, literacy, and mathematics skills. The qualitative analysis highlighted specific literacy and mathematics concepts identified for integration with CT lessons. The study identifies barriers to CT integration, provides insights for future PD efforts, and offers practical ideas for integrating CT to enhance K-2 literacy and mathematics instruction.

Ocak et al. (2023) analyse pre- and post-professional development (PD) surveys to examine teacher education faculty's perceptions of integrating unplugged computational thinking (CT) for pre-service education. Their paired sample t-test results revealed a significant increase in teacher educators' confidence and ability to

integrate unplugged CT after the PD. Qualitative analysis of open-ended responses showed shifts in their understanding of unplugged CT, framing it as a new literacy essential for teaching and learning in technology-enhanced environments and as a cross-cutting concept. Post-PD, teacher educators also viewed unplugged CT as a metacognitive pedagogical skill that helps pre-service teachers improve their teaching practice. Their study highlights emerging themes, such as unplugged CT being perceived as a transdisciplinary metacognitive skill and a new literacy practice, offering insights into the evolving perspectives and activities of teacher educators toward unplugged CT integration.

Mumcu et al. (2023) explore the integration of computational thinking (CT) into mathematics education through an unplugged computer science (CS) activity. Their research examines classroom practices and the perceptions of students and pre-service teachers regarding this integration. An unplugged CS activity was developed, focusing on efficiently transmitting data between a transmitter and receiver, incorporating CT components and educational goals in both computer science and mathematics. Twelve pre-service teachers were trained to integrate this activity with 80 middle school students across four classes. Their activity involved students in data collection, data analysis, decomposition, pattern recognition, algorithm design, and testing and debugging. Students reported enjoying the activity and found it enhanced their mathematics learning experience, although they struggled to connect it to broader CS concepts. Pre-service teachers noted challenges with classroom management, highlighting the need for teacher education programs to include training in classroom management, CS activity design, and integration. Their study suggests that integrating CT into mathematics education can be effective and enjoyable for students, provided

that teachers receive comprehensive training that combines theoretical and practical components specific to their discipline.

Tankiz and Atman Uslu (2023) examined the computational thinking (CT) skills and self-efficacy (SE) of thirty-seven pre-service teachers who participated in a course integrating educational game development in a block-based programming environment with the creation of corresponding lesson plans. Using convergent parallel mixed-method activities, with a quasi-experimental pretest-posttest design and thematic analysis, the study was conducted in three stages: awareness of CT components and Scratch programming, development of subject-specific Scratch-based games, and preparation of CT teaching lesson plans. Findings indicated significant improvements in both CT skills and SE, with a weak effect size for CT skills and a large effect size for SE. Qualitative data supported these results, with participants noting enhancements in their CT skills, SE, and overall professional competencies, particularly in technological and pedagogical knowledge.

James (2023) investigates fifth-grade mathematics teachers' knowledge and perceptions of computational thinking (CT) and CT skills, crucial for understanding rigorous secondary education coursework. The researcher explores how CT concepts like decomposition, patterns, algorithms, and abstraction are integrated into the curriculum. Using case study activities with five practising mathematics teachers, including a screener, questionnaire, and follow-up interview, the research employs deductive analysis and thematic decomposition to address key research questions. Findings reveal varied teacher perceptions, unclear definitions, and differing philosophies on efficiencies and algorithms, influencing the modelling of CT skills to students. The researcher underscores opportunities for enhancing abstraction in teacher and student

understanding and highlights the need for further research in early education. It suggests that targeted teacher training, professional development, curriculum design, and coaching could significantly impact student achievement, confidence, and STEM field engagement. The researcher initiates a pathway for integrating and refining CT knowledge in educational practice, starting with teachers as pivotal distributors and evaluators of knowledge in classrooms.

Jeong et al. (2023) examine the impact of integrating unplugged activities and Micro into a mathematics course on pre-service teachers (PSTs) self-efficacy, attitudes, and emotions at the Teacher Training School of the University of Extremadura in Cáceres. Utilising both quantitative measures and qualitative surveys, their study found that the intervention positively influenced PSTs' affective domains by enhancing their self-efficacy, attitudes, and emotions toward the course. The introduction of unplugged activities effectively helped PSTs understand abstract mathematical concepts, facilitating a smoother transition to using the Micro for visual programming within the Future Classroom Lab (FCL). The results underscore the benefits of such methodologies in providing effective support to PSTs, suggesting that these practices can improve teaching and learning experiences when incorporating new technological tools in education.

Jin and Harron (2023) investigated in-service teachers' perceptions and development of computational thinking (CT) skills within an online graduate emerging technologies course. Given the importance of computer science (CS) and CT in K-12 education and the lack of preparation among teachers for integrating these competencies, the study aimed to address this gap. The course was framed around the four cornerstones of CT: abstraction, algorithms, decomposition, and pattern recognition. Results indicated that

participants felt they improved in CT problem-solving and creativity skills. However, they also perceived a decrease in collaborative learning and critical thinking skills. Their study highlights the need for more specialised courses and research to support teachers in effectively integrating CS and CT into their curricula.

Ocak et al. (2023) investigate how teacher educators integrate computational thinking (CT), including unplugged methods, into pre-service teacher education. Conducted with 31 educators from diverse disciplines in a Northeastern US university, this research forms part of a year-long professional development initiative. Their program utilised virtual meetings and an asynchronous virtual classroom to integrate CT and unplugged activities into teaching practices. Analysis of pre- and post-surveys demonstrated a significant enhancement in educators' confidence and capability to integrate CT, supported by paired sample t-test results. Qualitative findings revealed that educators perceive CT, including unplugged methods, as a pivotal new literacy and cross-cutting concept crucial for teaching in technology-enhanced environments. They also recognised CT as a metacognitive pedagogical skill benefiting pre-service teachers in refining their teaching practices. Their study underscores CT's role as a transdisciplinary pedagogical skill and new literacy, enriched through unplugged computational thinking methods.

Hershkovitz et al. (2023) explore high school STEM teachers' perceptions of the impact of computational thinking (CT) and unplugged computational activities in mathematics on their classrooms following a four-week professional development program. This qualitative research, involving eight teachers, analysed exit interviews to understand how the program facilitated holistic growth in content knowledge, technology integration, and pedagogical strategies. The program's design, which involved teachers

first as CT learners using unplugged computational activities in mathematics and then as collaborators with educational researchers and computational experts in co-designing curricula, led to a significant shift in teachers' views. They reported a deeper understanding and appreciation of how CT, technology, and unplugged activities can positively transform their teaching practices and student learning experiences. Their study underscores the importance of collaborative and immersive professional development in reshaping educators' perceptions and enhancing STEM education.

Richardo et al. (2023) address the influence of gender differences on Computational Thinking (CT) skills and attitudes, and their correlation with CT skills, specifically in the context of mathematics subjects. Their research aims to bridge this gap. Their study employed quantitative descriptive activities with a comparative and correlational design. Participants included students from a junior high school in Yogyakarta, Indonesia (N=92). Data collection involved a mathematical problem-solving test to measure CT skills and a questionnaire to assess CT attitudes. Multivariate and simple linear regression analyses were conducted for data analysis. Their findings include the observation that female students demonstrate better CT skills in solving mathematical problems compared to boy students. However, there is no significant difference in CT attitudes between boys and girls. Additionally, the study reveals a significant relationship and influence of CT attitudes on CT skills. This research contributes to understanding the dynamics of CT skills and attitudes in the context of mathematics education, particularly regarding gender differences. It highlights the importance of considering attitudes alongside skills development in fostering computational thinking abilities among students.

Mumcu et al. (2023) explore the integration of computational thinking (CT) into mathematics education using an unplugged computer science (CS) activity. Their study focuses on integrating an activity designed to transmit data efficiently and accurately between a transmitter and receiver, involving CT components such as data collection, analysis, decomposition, pattern recognition, algorithm design, and testing/debugging. Twelve pre-service teachers were trained to integrate this unplugged CS activity with 80 middle school students across four classes. Feedback from students indicated enjoyment and satisfaction with the activity, though they expressed a need for better integration with CS concepts. Pre-service teachers highlighted challenges in classroom management during the activity, suggesting the importance of integrating classroom management into teacher education for designing and integrating CT-integrated lessons effectively. Their study recommends developing courses that blend theory and practice, focusing on CS activity design, integration, and classroom management for pre-service teachers within their disciplinary contexts.

Rajapakse-Mohottige et al. (2024) investigate the perspectives of 17 teacher educators (TEds) on incorporating computational thinking (CT), including unplugged activities, into primary teacher education mathematics and science courses in Norway, two years after CT's introduction into primary schools. Through a data-driven thematic analysis of semi-structured interviews, their study identifies challenges and opportunities at four levels: systemic, teacher educator, student teacher, and subject levels. Their findings indicate that integrating CT, especially using unplugged methods, into existing courses is complex but also presents significant benefits. Their insights are valuable for stakeholders looking to understand and improve the integration of CT into teacher education, thereby enhancing professional digital competence.

The literature review highlights students' positive perceptions of unplugged computational thinking (CT) activities, particularly in enhancing their understanding of abstract mathematical concepts. Students reported increased engagement, enjoyment, and a deeper understanding of problem-solving techniques through hands-on activities. They also noted improvements in logical thinking and the ability to recognise patterns and decompose problems. Overall, students appreciated the practical application of unplugged CT activities in mathematics, with some highlighting the benefit of unplugged activities in making the concepts more accessible and enjoyable. These perceptions suggest that unplugged CT activities can effectively support students' learning and mathematical development.

2.5.7 Challenges in Teaching and Learning CT through Unplugged Activities

Integrating unplugged activities in mathematics education presents unique challenges for students, despite their potential to enhance conceptual understanding and problem-solving skills. This review delves into the specific challenges students face when engaging with unplugged activities in mathematics.

Yeni et al. (2021) address the increasing emphasis on integrating Computational Thinking (CT) into various K-12 subjects and investigate teachers' pedagogical content knowledge (PCK) regarding CT. Their study utilised case studies where CT was integrated into these subjects. Following the lesson series, interviews were conducted to understand teachers' PCK, attitudes, and the challenges they faced. Their results indicated that CT-integrated lessons allowed students to delve deeper into subject content and effectively use digital technologies to solve related problems. However, teachers noted that both students and teachers need enhanced technical knowledge and skills to complete CT tasks.

Feng and Yang (2022) examine elementary school teachers' perspectives on integrating unplugged computational thinking (UCT) curriculum into classrooms, aiming to address STEM education disparities among K-12 students. Their study involves interviews with 12 teachers who participated in a National Science Foundation-funded STEM+C initiative. These teachers integrated project-based learning (PBL) activities into CT in after-school programs for 4th to 6th graders. Half of the teachers adapted the STEM+CT curriculum for their classrooms. The researchers explore teachers' perceptions of the value of UCT, challenges faced during integration, and their recommendations for overcoming these challenges. While all teachers encountered similar obstacles, those who adapted the curriculum emphasised CT's role in fostering complex problem-solving skills. They also advocated for enhanced teacher professional development focused on integrating CT effectively into elementary education. Their study underscores the importance of a tailored CT curriculum and ongoing support for educators to optimise student learning outcomes in STEM fields.

Sun et al. (2021) conducted an 8-week quasi-experimental study to evaluate the effectiveness of unplugged programming activities in enhancing computational thinking (CT) skills among 7th-grade students, given the growing importance of CT in the 21st century and disparities in programming education resources across Chinese junior high schools. Their study included 93 participants, with 62 students in experimental groups exposed to unplugged activities and 31 in a control group. Significant improvements in CT skills were observed among students participating in unplugged programming, regardless of their prior mathematics performance or programming experience. Challenges in the integration included adapting the unplugged activities to suit diverse student backgrounds and educational settings, as well as ensuring equitable access to necessary materials and resources across schools

with varying capabilities. Their challenges underscore the need for tailored activities to effectively integrate unplugged programming into junior high school curricula.

Kong and Lai (2022) developed a computational thinking (CT) teacher development framework based on the Technological Pedagogical Content Knowledge (TPACK) model, aimed at K-12 educators. The framework integrates Technological Content Knowledge (TCK), Computational Knowledge (CK), Pedagogical Content Knowledge (PCK), and TPACK to enhance CT education. TCK involves utilising block-based programming with advanced features, CK focuses on understanding CT concepts, and PCK emphasises pedagogical strategies like unplugged activities and project-based learning. Their study integrated structured seven-step activities to integrate CT into curriculum content, which included revisiting TCK for advanced features, consolidating CK, and refining PCK strategies. Challenges encountered included difficulties in designing effective unplugged activities aligned with CT concepts and integrating them seamlessly into existing curricula while meeting educational standards. Despite these challenges, the framework proved effective in enhancing teachers' CT instruction, highlighting the importance of structured professional development in advancing CT education.

Voon et al. (2023) conducted a study aimed at enhancing pre-service teachers' computational thinking (CT) skills through experiential learning. Recognising CT's critical role in problem-solving in today's technology-driven society, their study addressed gaps in research on pre-service teachers' CT competencies. Employing hybrid activities that included both plugged and unplugged CT activities, the researchers developed a twelve-week module to help participants integrate CT into their lesson planning. Despite the benefits of unplugged activities in fostering deeper

conceptual understanding, their study faced logistical challenges such as scheduling constraints and the availability of suitable physical spaces for conducting hands-on unplugged activities. Nonetheless, the module successfully improved participants' CT competencies, as evidenced by their enhanced ability to integrate, justify, and reflect on CT in their lesson plans. Their research underscores the importance of providing practical CT training, leveraging both plugged and unplugged methods, to equip pre-service teachers with essential skills for effective teaching in the digital age.

Based on the literature review, students and pre-service teachers face several challenges when engaging with computational thinking (CT) activities in mathematics. One key challenge is the difficulty in integrating CT with existing curricula, which requires significant adjustments in teaching strategies. Additionally, students often lack prior exposure to CT concepts, making it harder for them to fully engage with the activities. Resource limitations, such as insufficient instructional materials and suitable spaces for hands-on activities, further hinder the effective integration of CT. Time constraints and the need to balance CT with traditional teaching methods also present significant barriers to successful integration.

2.6 Gap in Literature

Research on unplugged activities has advanced significantly, highlighting their effectiveness in enhancing computational thinking (CT) skills and 21st-century skills among students, pre-service teachers, and in-service teachers. Numerous international studies have contributed to this growing body of evidence, including notable work by Fanchamps et al. (2024), Yılmaz & İzmirli (2023), El-Hamamsy et al. (2022), and del Olmo-Muñoz et al. (2020).

Fanchamps et al. (2024) conducted a comparative study examining the effects of unplugged smart games versus structured programming activities with tangible or on-screen outputs on primary school students' CT skills. Their findings indicated that unplugged smart games were as effective as traditional programming activities in fostering CT skills. More importantly, their study emphasised that unplugged activities facilitated a deeper understanding of essential CT principles such as decomposition, pattern recognition, and algorithmic thinking. These principles are not only foundational to CT development but are also closely aligned with core competencies like critical thinking, problem-solving, and independent learning, skills that are central to 21st-century education.

Yılmaz & İzmirli (2023) study revealed significant improvements in students' problem-solving skills and their capacity to address mathematical challenges through unplugged activities. Their research showed that unplugged CT activities promoted creativity and analytical thinking, key competencies for learners and teachers in competency-based education systems.

El-Hamamsy et al. (2022) focused on developing and validating the Competent Computational Thinking Test for upper primary school students. Their findings revealed that unplugged activities not only helped pre-service teachers grasp abstract CT concepts such as algorithms and abstraction but also contributed to strengthening their content knowledge and instructional delivery. These improvements are directly linked to core competencies such as personal development, communication, and reflective practice.

Del Olmo-Muñoz et al. (2020) study revealed substantial improvements in students' problem-solving capabilities and their engagement with mathematical concepts through

unplugged activities. Their research underscored the profound effect of unplugged activities on learners' ability to think critically, collaborate effectively, and communicate ideas clearly, competencies necessary for both academic success and lifelong learning.

Significant research has also been conducted in Africa, particularly in West and Southern Africa. Studies by Agbo et al. (2024) in Nigeria, Greyling (2023) in South Africa, Tshukudu et al. (2023) in Uganda, and Kassa & Mekonnen (2022) in Ethiopia provide valuable insights into the effectiveness of unplugged CT activities in developing core competencies.

Agbo et al. (2024) examined the impact of unplugged activities on secondary school students in Nigeria, reporting marked improvements in learners' ability to decompose complex problems and develop efficient algorithms. These activities fostered independent thinking and resilience, essential components of personal development and critical thinking competencies.

Greyling (2023) explored the use of unplugged activities in South African classrooms, with a focus on in-service teachers. The study revealed that teachers who implemented these activities developed greater confidence in teaching computational concepts and reported improvements in student collaboration and classroom engagement. These outcomes reflect growth in teacher competencies such as innovation, professional confidence, and facilitation of student-centred learning.

Tshukudu et al. (2023) investigated the effects of unplugged activities on pre-service teachers in Uganda, revealing significant enhancements in their computational thinking skills and instructional capabilities. The study concluded that unplugged activities

promote a shift from rote-based teaching to inquiry-driven pedagogy, reinforcing key competencies such as creativity, communication, and learner-focused planning.

Kassa & Mekonnen (2022) conducted research in Ethiopia and found that unplugged activities significantly improved students' problem-solving abilities and understanding of pattern recognition and algorithmic thinking. These skills translate into broader competencies such as digital literacy, logical reasoning, and effective decision-making. Despite the growing global body of research highlighting the benefits of unplugged activities for pre-service teachers, a notable knowledge gap remains in the Ghanaian context. Specifically, there is limited empirical evidence on how unplugged CT activities can be integrated within pre-service teacher education to foster core competencies.

This presents both pedagogical and literature gaps. Pedagogically, pre-service teachers in Ghana often lack hands-on, experiential learning opportunities that integrate CT principles with core competencies such as creativity, collaboration, and reflective thinking. From a research perspective, few empirical studies in Ghana have examined the feasibility, challenges, and impact of using unplugged CT activities to promote both CT skills and broader educational competencies in teacher education.

Furthermore, existing literature predominantly emphasises quantitative assessments that measure improvements in CT skills and conceptual understanding of mathematics. However, qualitative aspects, such as pre-service teachers' experiences, reflections, and perceived challenges when using unplugged activities, remain underexplored. Addressing this methodological gap through qualitative or mixed-methods research will yield deeper insights into the holistic development of pre-service teachers.

While significant progress has been made globally in understanding the effectiveness of unplugged CT activities, focused research within the Ghanaian teacher education system is urgently needed. Such research should explore not only improvements in CT skills but also how unplugged CT activities can nurture the core competencies outlined in Ghana's Standards-Based Curriculum and the National Teacher Education Curriculum Framework. Bridging this gap will help produce more competent, innovative, and learner-centred mathematics educators equipped to meet the demands of 21st-century education.

2.7 Summary of the Chapter

Chapter two explores five themes: theoretical review, conceptual review, empirical review, theoretical framework, and conceptual framework. Theoretical review covers learning theories supporting computational thinking (CT) integration. Conceptual review explains CT components and unplugged activities. Empirical review examines global and Ghanaian studies. Theoretical and conceptual frameworks outline guiding theories and relationships among constructs. The chapter identifies research gaps shaping this study.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Introduction

This chapter outlines key aspects of the research, including philosophical framework, research approach, research design, population, sample, sampling techniques, instrumentation, data collection procedure, pilot testing, measures for validity and reliability, data analysis procedure, and ethical considerations

3.1 Research Paradigm and the Philosophical Position of the Study

Research paradigms form the foundational philosophy that guides how a study is conceptualised, designed, and executed, shaping choices about methods and analysis (Alharahsheh & Pius, 2020; Ganiyu et al., 2020). A paradigm represents a set of beliefs and assumptions that keep the research process logically connected to the research questions. This study is grounded in pragmatism, which prioritises real-world outcomes and provides a practical framework for tackling complex, context-dependent issues in education. It supports the production of actionable knowledge, making it an appropriate lens for evaluating how Unplugged Computational Thinking Activities in Mathematics (UCTAM) can enhance pre-service teachers' computational thinking skills.

Epistemologically, pragmatism holds that knowledge is created through practical engagement with real-world problems (Hirose & Creswell, 2023), aligning with the study's goal of investigating how hands-on tasks help pre-service teachers acquire and apply computational thinking skills in mathematics. The epistemological stance is reinforced by constructionism, which proposes that learners build understanding by actively creating and manipulating artefacts in meaningful contexts (Papert, 1980), and

by experiential learning theory, which argues that knowledge develops through direct experience, reflection, and application (Kolb, 1984).

Ontologically, pragmatism adopts a pluralistic stance, recognising that reality is constructed through diverse experiences and contexts (Hirose & Creswell, 2023). This view aligns with understanding how pre-service teachers with varied backgrounds interact with UCTAM, acknowledging that computational thinking can be developed through multiple pathways shaped by context. It also justifies design choices such as qualitative focus groups to capture these diverse realities.

Axiologically, pragmatism recognises that researchers' values influence the research process but maintains that knowledge must be practically beneficial (Hirose & Creswell, 2023). This demonstrates the researcher's dedication to enhancing mathematics education and improving teacher training by meaningfully integrating computational thinking.

Methodologically, pragmatism supports mixed methods research because it prioritises using the most suitable tools to address practical problems (Clark & Clark, 2022). This study combines objective assessments, such as computational thinking performance tests, with thematic analysis of interviews to ensure that both measurable outcomes and contextual factors are captured.

3.2 Research Approach

The study adopted a mixed methods research approach. The approach was considered appropriate because the research objectives required both measuring changes in computational thinking skills and exploring pre-service teachers' experiences during the intervention. Mixed-methods approach enables the integration of quantitative and qualitative data within a single study to generate a more comprehensive understanding of a research problem (Hirose & Creswell, 2023).

In this study, quantitative data provided empirical evidence of the effectiveness of the Unplugged Computational Thinking Activities in Mathematics (UCTAM) in improving computational thinking skills, while qualitative data offered explanatory insights into pre-service teachers' perceptions and experiences during the intervention. The combination of these two methods allowed the study to capture both measurable outcomes and in-depth contextual meanings.

The integration of quantitative and qualitative findings strengthened the overall interpretation of the results. Drawing on both numerical evidence and pre-service teachers' perspectives, the study provided a more holistic understanding of the impact of the intervention within the teacher education context.

3.3 Research Design

The study employed an explanatory sequential design (Hirose & Creswell, 2023). This design involves collecting and analysing quantitative data first, followed by qualitative data to explain and contextualise the quantitative findings. Explanatory sequential design was considered appropriate because the study aimed to both measure changes in pre-service teachers' computational thinking skills and explore their experiences with

the Unplugged Computational Thinking Activities in Mathematics (UCTAM). Figure 2 illustrates the two sequential phases of the study.

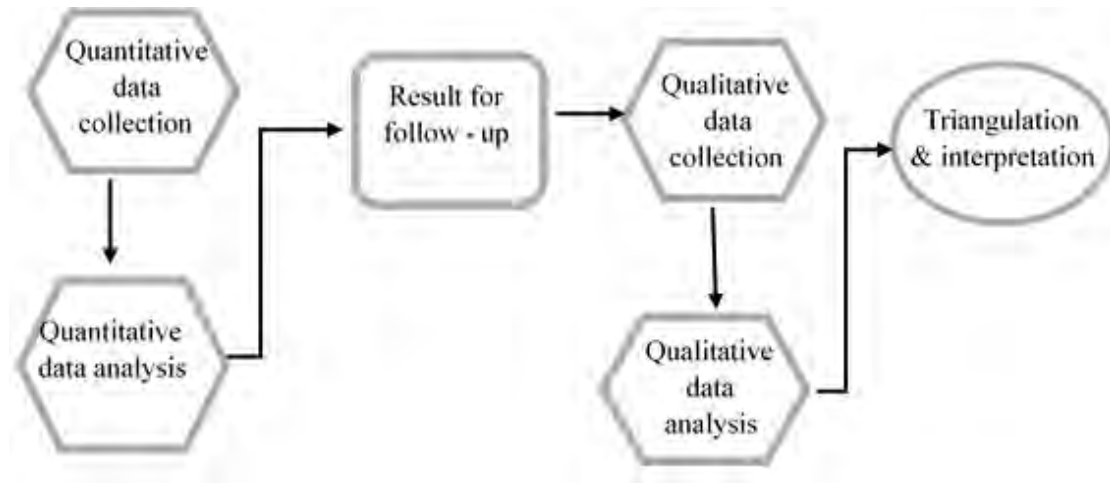


Figure 2: Explanatory Sequential Design

The first phase utilised the Unplugged Computational Thinking Mathematics Skills Test (UCTMST) to assess pre-service teachers' computational thinking skills before and after their engagement with Unplugged Computational Thinking Activities in Mathematics (UCTAM). This provided objective data to identify changes in skills throughout the intervention.

The second phase involved focus group discussions, which provided insights into pre-service teachers' experiences, perceptions, and challenges with UCTAM. These discussions offered perspectives not captured by quantitative assessments alone, enriching understanding of UCTAM's impact on their computational skills and pedagogical practices.

Integrating quantitative and qualitative data ensured a comprehensive understanding of UCTAM's effects. This dual focus on measurable outcomes and pre-service teachers' experiences aligns with a pragmatic perspective, enhancing the credibility of findings

and providing a holistic view of how UCTAM influenced computational thinking skills, confidence, and engagement within the context of Ghanaian Colleges of Education.

3.4 Population

The researcher adopted a pragmatic paradigm in determining the population for the study on the effect of unplugged computational thinking activities in mathematics (UCTAM) on pre-service teachers' computational thinking skills. The pragmatic paradigm, as described by Gobo and Marcheselli (2023) and Hirose and Creswell (2023), emphasises flexibility, practical relevance, and real-world application of research results. In line with this, the study focused on a population that would not only provide rich, relevant data but also demonstrate knowledge on effective integration of unplugged computational thinking activities in mathematics.

The target population comprised all pre-service teachers enrolled in the seven public Colleges of Education in the Volta Region of Ghana during the 2022–2025 academic years, amounting to a total of 8,269 pre-service teachers (Colleges of Education Admission Unit, 2024)

However, with the pragmatic paradigm's emphasis on purposeful and contextually appropriate sampling, the study narrowed its scope to an accessible population of 1,550 Level 200 pre-service teachers in the Colleges of Education. These pre-service teachers were selected because they had already completed foundational mathematics courses and are in their second year, making them adequately prepared to engage meaningfully with the UCTAM intervention. Table 1 shows a breakdown of both the target and accessible populations across the seven public Colleges of Education in the Volta Region.

Table 1: Target and accessible population of pre-service teachers in Volta Region Colleges of Education

Institution	Target Population (All Levels)	Accessible Population (Level 200)
E.P. College of Education, Amedzofe	1,141	215
Peki College of Education	1,073	245
St. Teresa's College of Education, Hohoe	1,227	210
Dambai College of Education	1,185	230
Akatsi College of Education	1,317	220
Jasikan College of Education	1,095	225
St. Francis College of Education, Hohoe	1,231	205
Total	8,269	1,550

Source: Institutional Records / Field Data (2024)

The selection enabled the researcher to draw from a well-prepared and contextually relevant participant group, ensuring the findings would be both practically applicable and educationally impactful within similar teacher education settings.

3.5 Sample and Sampling Techniques

The study involved 87 Level 200 pre-service teachers specialising in Primary Education. Two intact classes were selected: one class served as the experimental group (n = 44, Evangelical Presbyterian College of Education, Amedzofe) and the other as the control group (n = 43, Peki College of Education). The groups were classified based on pre-test performance to ensure comparable levels of computational thinking skills before the intervention. Using intact classes preserved the natural classroom environment and ensured similar academic backgrounds, enhancing internal consistency of the intervention outcomes (Gobo & Marcheselli, 2023).

The two colleges were purposively chosen because both follow the Bachelor of Education (B.Ed.) curriculum designed by the University of Education, ensuring

comparable academic preparation among pre-service teachers. Within these colleges, Primary Education pre-service teachers were purposively selected because their course structure is aligned and provides a stronger foundation in mathematics compared to Junior High School (JHS) and Early Grade Education programs. This ensured that pre-service teachers engaged effectively with UCTAM and provided meaningful reflections on its effects on computational thinking skills and teaching practices (Hirose & Creswell, 2023).

Convenience sampling was also applied for practical reasons, including accessibility, proximity of the colleges, and the researcher's professional role as a mathematics tutor at one of the institutions. This approach allowed efficient coordination, timely data collection, and cost-effective intervention implementation.

The combined use of purposive and convenience sampling ensured that pre-service teachers were both relevant to the study objectives and practically accessible. According to Creswell and Hirose (2023), a sample size of 30 to 120 pre-service teachers is sufficient for meaningful statistical analysis in social science studies. With 87 pre-service teachers, the sample falls within this recommended range, providing adequate statistical power while maintaining methodological rigour.

3.6 The Experiment Procedure

The experiment employed two instructional approaches: the Unplugged Computational Thinking Mathematics Instructional Activities (UCTAM) approach and the traditional instructional approach (TIA). The aim was to compare the effectiveness of these approaches in enhancing pre-service teachers' computational thinking skills.

3.6.1 Unplugged Computational Thinking Activities in Mathematics

The researcher started the implementation of UCTAM by developing an eight-week instructional module, designed to integrate unplugged computational thinking activities: decomposition, pattern recognition, abstraction, and algorithmic thinking. The instructional module was supported by various hands-on learning materials, including number charts, algebra tiles, and flowchart templates, all created by the researcher to facilitate interactive and engaging lessons.

In the first week, the focus was on decomposition. Pre-service teachers worked with geometric shapes such as rectangles, squares, and triangles. The activity required them to measure and categorise the shapes, breaking them down from smallest to largest. This activity developed their decomposition skills, a core component of computational thinking, as they broke down complex shapes into simpler components. Materials such as shape cut-outs and measuring tapes were used to reinforce spatial awareness and measurement concepts.

In week 2, the focus of the UCTAM approach shifted to applying decomposition within algebra. The pre-service teachers in the experimental group were introduced to algebra tiles, which allowed them to break down and simplify multi-step linear equations. The activity involved solving problems using distribution and combining like terms, helping them visualise the algebraic processes. By manipulating the tiles, pre-service teachers could decompose complex equations into smaller parts, reinforcing their problem-solving skills.

In week 3, the focus of the UCTAM approach was on recognising and extending number sequences, such as triangular numbers, square numbers, and pentagonal numbers. The researcher developed number charts and pattern blocks, and pre-service

teachers were to visually identify the patterns and generate the next numbers in the sequence. These activities aimed to develop their pattern recognition skills, another key component of computational thinking.

The emphasis of the UCTAM approach in week 4 was on recognising and extending patterns in geometric shapes. Pre-service teachers used shape tiles and graph paper to explore how shapes like triangles, squares, and pentagons could form tessellations or sequences. Pre-service teachers worked on generating new shapes by continuing the identified patterns and applying their pattern recognition skills to both geometric and numerical contexts.

In week 5, pre-service teachers engaged in two key activities. First, they worked with number charts ranging from 1 to 100 to identify and classify numbers. They abstracted prime numbers, odd numbers, and composite numbers, using highlighters to colour-code each category. This task reinforced their understanding of number properties. Concurrently, pre-service teachers used shape cut-outs and graph paper to explore geometric abstraction, combining simple shapes like rectangles, squares, and triangles to form new, more complex shapes.

In week 6, the researcher revisited number classification with fresh number charts, further refining the skills developed in week 5. Pre-service teachers identified and abstracted various types of numbers, ensuring accuracy in their classification tasks. Additionally, they worked on advanced geometric abstraction tasks, using shape tiles and rulers to explore how combining different shapes can create more complex figures. In week 7, the focus shifted to algorithmic thinking, starting with linear equations. Pre-service teachers were introduced to flowchart templates, calculators, graph paper, and instructional cards to develop algorithms for solving systems of linear equations. The

activity focused on methods such as substitution and elimination, with flowcharts helping them visualise the steps involved. Pre-service teachers used calculators to carry out computations and graph paper to represent solutions. Additionally, they explored matrix operations for solving linear systems, utilising grid paper and matrix guides to perform row operations through Gaussian elimination.

In week 8, pre-service teachers continued applying algorithmic thinking, focusing on graphical methods for solving linear equations. Using graph paper, rulers, coloured pencils, and plotting guides, they developed algorithms for plotting linear equations on a coordinate plane. Pre-service teachers were tasked with solving linear inequalities, using graph paper and coloured pencils to represent inequalities and shading feasible regions. This hands-on approach helped them visualise the relationship between algebraic equations and their graphical representations.

Throughout the 8 weeks, the UCTAM progressively developed computational thinking skills. Each week built on the previous one, ensuring that pre-service teachers not only learned key mathematical concepts but also integrated computational thinking principles such as decomposition, pattern recognition, abstraction, and algorithmic thinking into their learning. The activities were designed to be hands-on and engaging, helping pre-service teachers understand the relevance and application of computational thinking in real-world contexts. For detailed information on the instructional activities, the full plan can be found in Appendix E.

3.6.2 Traditional Instructional Activities for Teaching Mathematics (TIA)

In contrast to the experimental group's engagement with the Unplugged Computational Thinking Activities in Mathematics (UCTAM), the control group followed structured traditional teaching methods. The UCTAM and traditional instructional activities (TIA)

aimed to establish a baseline for comparing the effectiveness of UCTAM in enhancing pre-service teachers' computational thinking skills. The teaching modules for the control group were designed in alignment with the learning objectives outlined in the syllabus.

At the preparation stage, the researcher undertook careful planning to ensure that the lessons for the control group would be effective and aligned with the desired learning outcomes. The researcher reviewed the curriculum and syllabus to determine the specific mathematical content that needed to be covered. The researcher also prepared relevant teaching materials, including detailed chalkboard illustrations, mathematical charts, and other necessary resources for class exercises. The preparation helped ensure that each lesson was well-paced and clear, and supported pre-service teachers in gradually building their understanding.

During the first week, the researcher introduced pre-service teachers to the decomposition of basic geometric shapes, focusing on rectangles, squares, and triangles. Using the chalkboard, the researcher illustrated how to measure and classify the shapes into the smallest, small, medium, larger, and largest. The researcher drew each shape on the board, explaining step-by-step how to calculate their dimensions. Pre-service teachers followed along, taking notes and making sketches in their notebooks to reinforce the lesson.

In the second week, the focus shifted to applying decomposition concepts in algebra. The researcher introduced the concept of solving multi-step linear equations using the chalkboard for demonstrations. The researcher broke down complex equations into smaller, manageable parts, showing how to distribute terms and combine like terms. The approach allowed pre-service teachers to visually track each step of the process as

the researcher wrote out the equations and solutions on the board, helping them understand the underlying structure of algebraic equations.

During the third week, the lesson centred on recognising patterns in number sequences. The researcher used the chalkboard to display sequences of triangular numbers, square numbers, and pentagonal numbers. The researcher demonstrated how to identify patterns in these sequences by writing out the numbers and drawing connections between them. After observing the patterns on the board, pre-service teachers were asked to continue the sequences in their notebooks, which helped solidify their understanding of how numerical patterns evolve.

In the fourth week, the emphasis was on recognising patterns in geometric shapes. The researcher used the chalkboard to draw various geometric shapes such as triangles, squares, and pentagons, illustrating how these shapes could form sequences or tessellations. The researcher explained the patterns step-by-step, encouraging students to replicate the process in their notebooks. By continuing the identified patterns on paper, pre-service teachers applied their understanding of pattern recognition in a geometric context, reinforcing the concepts through traditional board illustrations.

During the fifth week, pre-service teachers were engaged in number classification tasks using the chalkboard. The researcher wrote out a number chart ranging from 1 to 100 and led the class in identifying and categorising prime numbers, odd numbers, prime composite numbers, and odd composite numbers. Each category was colour-coded using chalk, and pre-service teachers copied the chart into their notebooks, reinforcing their understanding of number properties and classification. The class also explored geometric abstraction, with the researcher drawing rectangles, squares, and triangles on the board, demonstrating how to combine these shapes to form new ones. Pre-service

teachers sketched these combinations in their notebooks, discussing the possibilities and limitations of different shapes.

In the sixth week, the researcher revisited number classification, using a fresh number chart on the chalkboard. The researcher guided pre-service teachers through the identification and abstraction tasks again, reinforcing accuracy and comprehension. Alongside this, the researcher introduced an advanced geometric abstraction task. The researcher used the chalkboard to illustrate how various geometric shapes could be combined to form new figures. Pre-service teachers copied these examples into their notebooks, exploring how some shapes could easily be combined to create complex structures, while others were less versatile. The approach deepened pre-service teachers' understanding of geometric properties through visual and hands-on board illustrations.

During the seventh week, the focus shifted to algorithmic thinking with a concentration on solving linear equations. The researcher used the chalkboard to outline the process of solving systems of linear equations, such as the substitution and elimination methods. The researcher drew flowcharts on the board to visualise the step-by-step procedures and demonstrated how to solve these systems manually. Pre-service teachers followed the process in their notebooks, using calculators to carry out the computations as the researcher guided them through each step.

In the eighth week, pre-service teachers continued applying algorithmic thinking to linear equations, this time focusing on graphical methods. The researcher used the chalkboard to draw coordinate planes and plot linear equations. The teacher demonstrated how to draw lines and identify intersection points that represent solutions to systems of equations. Pre-service teachers replicated these graphs in their notebooks,

using rulers and coloured pencils to ensure precision. The class also worked on solving linear inequalities, with the researcher illustrating how to represent inequalities on a graph and shade feasible regions. The approach centred on board illustrations, which helped students visualise and solve linear inequalities effectively.

3.7 Data Collection Instruments

The Unplugged Computational Thinking Mathematics Skills Test (UCTMST), observation guide, questionnaire, and focus group discussion were employed as the data collection instruments to provide a comprehensive and multi-dimensional analysis. The UCTMST and questionnaire are quantitative instruments, while the observation guide and focus group discussion serve as qualitative instruments. All these instruments align with the pragmatic view of selecting data collection instruments and integrating numerical data with in-depth qualitative insights to thoroughly address the research objectives.

3.7.1 Achievement tests (pre-test and post-test)

The Unplugged Computational Thinking Mathematics Skills Test (UCTMST) was made up of eight (8) items designed to assess participants' computational thinking constructs, including decomposition, pattern recognition, abstraction, and algorithmic thinking, within the context of algebra and geometry. These constructs were measured through a series of activities, corresponding to specific cognitive skills, adapted from online educational resources, such as [CS Unplugged.com](http://CSUnplugged.com) and Pinterest.com. These activities were chosen for their pedagogical validity and relevance to computational thinking frameworks.

The test consisted of eight (8) questions, with two questions each focusing on decomposition, pattern recognition, abstraction, and algorithmic thinking. Task 1

emphasised decomposition, required pre-service teachers to break complex geometric shapes into simpler components. This task evaluated their ability to simplify problems into manageable parts. For instance, the task in Figure 3 required pre-service teachers to decompose a composite shape into its constituent squares and count the total number of squares visible.

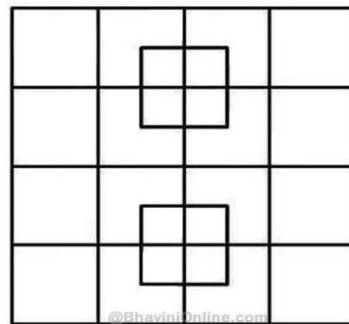


Figure 3: Squares Count Challenge

Task 2 expanded on this concept by asking pre-service teachers to decompose a complex shape into smaller triangular components and calculate the total count. This task further reinforced decomposition as a core skill in computational thinking, guiding pre-service teachers to systematically reduce larger figures into manageable units.

Task 3 moved to the next computational thinking construct, pattern recognition, by having pre-service teachers extend a sequence of square-dot patterns. They were tasked with predicting the sixth and seventh iterations and calculating the total number of dots in the tenth iteration. This task aimed to develop their ability to identify and generalise patterns, sharpening their skills in pattern recognition and prediction.

Task 4 introduced a more advanced challenge, combining square and circle patterns. Pre-service teachers were asked to extend the sequence and calculate the total number

of elements in the tenth iteration, requiring them to analyse relationships within combined patterns and refine their analytical and predictive abilities.

In task 5, pre-service teachers analysed a sequence of matchstick patterns to determine the number of matchsticks in the tenth iteration. They were also required to generalise a rule applicable to the iteration, further honing their abstraction skills by deriving insights from specific patterns.

Task 6 built on abstraction, introducing a more intricate sequence of matchstick patterns. Pre-service teachers completed a table for iterations up to the 50th and formulated a generalised rule for the iteration. This task encouraged them to process extensive data, identify underlying patterns, and develop scalable solutions.

Activities 7 and 8 focused on equations where shapes represented unknown values. Pre-service teachers analysed these equations to identify relationships among the shapes and deduce their values. These activities tested algorithmic thinking, requiring systematic, step-by-step reasoning and logical problem-solving to arrive at the correct solutions.

The tasks were developed to assess pre-service teachers' logical reasoning, procedural fluency, and clarity in problem-solving. The pre-test and post-test were designed with identical structures to ensure comparability, thus allowing for an accurate measurement of changes in computational thinking skills over time. The post-test, while maintaining the same format, included parallel but varied tasks to mitigate the risk of rote memorisation, thereby encouraging the application of newly acquired skills.

To ensure a comprehensive evaluation of cognitive skills, the test items were aligned with Bloom's taxonomy, addressing a broad range of cognitive abilities from basic

recall to higher-order thinking. The tasks were tailored to the educational backgrounds of the pre-service teachers, incorporating mathematical concepts such as geometric patterns and number sequences relevant to their curriculum.

The scoring method was designed to reflect pre-service teachers' ability to analyse, decompose, and solve problems systematically. For example, in the square-counting activity (Figure 4), the scoring criteria included:

1-unit by 1-unit squares (blue squares)	Q1B1
Number of 1-unit by 1-unit squares = 8	Q1A1
2-unit by 2-unit squares (green squares)	Q1B2
Number of 2-unit by 2-unit squares = 18	Q1A2
4-unit by 4-unit squares (green squares)	Q1B3
Number of 4-units by 4-unit squares = 9	Q1A3
6-unit by 6-unit squares (green squares)	Q1B4
Number of 6-unit by 6-unit squares = 4	Q1A4
8-unit by 8-unit squares (green squares)	Q1B5
Number of 8-units by 8-unit squares (outer square) = 1	Q1A5
Attempting to add a number of each size = $8+18+9+4+1$	Q1M1
Obtaining the correct number of possible squares = 40	Q1A6

Figure 4: Scoring Criteria for Square-Counting Activity

Scoring criteria were similarly applied to other activities, with partial marks for correctly identifying individual elements and full marks for summing all components accurately. The systematic scoring approach ensured fairness and consistency in evaluating pre-service teachers' computational thinking skills, particularly their abilities in decomposition and pattern recognition. Detailed scoring rubrics and test items are available in Appendices A and B for further reference.

3.7.2 Observation Guide

The observation guide was designed to document the behaviours, interactions, and problem-solving approaches of pre-service teachers (PSTs) in the experimental group during their engagement with the Unplugged Computational Thinking Activities in Mathematics (UCTAM). The observation guide aimed to collect qualitative data that would provide deeper insight into the differences in performance between the experimental and control groups. The observation guide examines PSTs at three critical stages of the UCTAM intervention: the beginning, middle, and final weeks. Each of these phases provided insights into the progression of PSTs' problem-solving abilities and their adaptation to the UCTAM methodology. Data were collected through structured field notes of classroom activities.

The observation guide was categorised into four major areas, each focusing on distinct aspects of PSTs' engagement with UCTAM. The categories included attacking the problems, strategies used in the problem-solving process, engagement—participation, collaboration, and communication, and affective qualities displayed. Each of these dimensions allowed for a comprehensive analysis of PSTs' development over time.

The first category, attacking the problems, focused on examining PSTs' ability to comprehend and interpret mathematical problems and the approaches to problem-solving tasks. At this phase, the researcher observed and documented whether PSTs demonstrated an initial understanding of the problem or struggled to identify a clear starting point. In addition, the researcher observed and documented PSTs' ability to break down problems, recognise patterns, and apply logical reasoning to determine how well they adapted to computational thinking concepts.

The second category is strategies used in the problem-solving process. At this phase, the researcher observed and documented specific problem-solving techniques employed by PSTs. Also, the researcher observed and documented the accuracy and appropriateness of these strategies to determine whether PSTs selected methods that were well-suited to the given tasks or struggled to identify effective approaches. Additionally, the researcher also observed and documented the extent to which PSTs applied fundamental computational thinking principles, including decomposition, pattern recognition, and abstraction.

The third category was engagement, participation, collaboration, and communication. The researcher at this phase observed and documented engagement through active participation in discussions, contributions to group activities, and attentiveness during UCTAM sessions. The researcher observed and documented whether PSTs took an active role in problem-solving tasks or remained passive, relying on their peers. Furthermore, the researcher observed and documented the extent to which PSTs collaborated to refine their problem-solving strategies, shared ideas, cooperated with peers, and provided constructive feedback.

The researcher also observed and documented PSTs' communication skills to examine how effectively they articulated their thought processes. The researcher observed whether PSTs could clearly explain their reasoning, justify their solutions, and consider alternative perspectives, which demonstrated strong computational thinking abilities. Additionally, the researcher observed and documented responsiveness to feedback, noting whether PSTs were willing to refine their approaches based on peer or instructor input.

The final category, affective qualities displayed, focused on the emotional and motivational attributes exhibited by PSTs, such as diligence, perseverance, confidence, and motivation. At this phase, the researcher observed and documented whether PSTs demonstrated persistence when faced with difficult problem-solving tasks or became easily discouraged. The researcher observed and documented PSTs' resilience, noting whether they persevered through challenges or abandoned tasks after initial setbacks.

The researcher also observed PSTs' confidence levels. The researcher observed whether their confidence levels increased or decreased as they engaged in UCTAM activities. Similarly, the researcher observed enthusiasm and motivation toward learning activities to determine whether PSTs' motivation increased or decreased throughout the UCTAM intervention.

Observations were conducted throughout the intervention period. The observation was divided into three key phases: beginning, middle, and final weeks, each offering insights into PSTs' learning progression. During the beginning weeks, observations focused on PSTs' initial reactions to problem-solving tasks, their baseline understanding of computational thinking concepts, and their overall engagement levels. The researcher observed PSTs' hesitations, initial strategies, and responsiveness to the UCTAM activities. This phase provided a foundation for examining how the intervention influenced their problem-solving behaviours over time.

In the middle weeks, attention was given to the evolution of problem-solving strategies, increased levels of collaboration, and improvements in engagement. The researcher observed how PSTs refined their approaches, demonstrated greater teamwork, and adapted their reasoning skills. The researcher observed shifts in affective qualities, such

as growing confidence and persistence, highlighting their willingness to engage with complex problems rather than resorting to guesswork or avoidance.

In the final weeks, the focus shifted to examining PSTs' mastery of problem-solving strategies, their ability to independently approach tasks, and their overall confidence in applying computational thinking principles. The researcher observed their increased proficiency in decomposition, pattern recognition, and abstraction, reflecting the impact of the intervention on their computational thinking abilities.

The researcher observed classroom interactions, in-class problem-solving tasks, group discussions, and peer interactions, providing rich qualitative data to complement quantitative findings.

3.7.3 Questionnaire

The questionnaire was designed to gather insights into pre-service teachers' perceptions of Unplugged Computational Thinking Activities in Mathematics (UCTAM). It was categorised into two, in alignment with the research framework and objectives, to ensure comprehensive data collection.

The first category, demographic information, was designed to collect data on pre-service teachers' background, including their age, gender, education, and teaching experience. This section comprises four items, each targeting a specific demographic variable to ensure a comprehensive understanding of the sample's diversity. Demographic information was essential for understanding the sample's diversity and for exploring potential patterns in responses based on these variables.

The second part consisted of ten items that specifically assessed the pre-service teachers' experiences with and perceptions of UCTAM. These items were designed to

evaluate several key aspects of their engagement with the activities, including perceived effectiveness in enhancing their understanding of mathematical concepts, fostering creativity and critical thinking, improving problem-solving skills, and increasing motivation to learn mathematics. Furthermore, the items explored participants' confidence in designing and implementing UCTAM in future lessons, as well as their views on the collaborative nature of these activities in the classroom. These aspects were broken down into sub-themes to ensure each dimension was adequately captured. For example, four items focused on engagement, three on problem-solving, and three on collaboration.

The questionnaire employed a five-point Likert scale type of items ranging from "strongly disagree" (1) to "strongly agree" (5), with a neutral midpoint (3) to allow respondents to express neutrality. This scale was chosen to assess the participants' level of agreement with statements regarding UCTAM across various dimensions, providing a reliable quantitative measure of their experiences.

The questionnaire items were adapted from established studies on unplugged computational thinking activities (Tsortanidou et al., 2023; Sun et al., 2021; Looi et al., 2018; Brackmann et al., 2017). Items in these studies were selected because they provided a robust framework for measuring computational thinking skills and the pedagogical effects of unplugged activities in mathematics. The items were then tailored to address the specific context of pre-service teachers, ensuring relevance to their understanding of mathematical concepts and teaching methods. A detailed questionnaire is provided in Appendix C.

3.7.4 Focus Group Discussion (FGD)

A Focus Group Discussion (FGD) was conducted to explore pre-service teachers' perspectives on the effectiveness and challenges of implementing Unplugged Computational Thinking Activities in Mathematics (UCTAM). Focus Group Discussion (FGD) was selected due to its ability to facilitate rich, interactive discussions. It allows participants to share diverse experiences, clarify their viewpoints, and build on each other's insights. This approach proved invaluable in gaining a deeper understanding of how UCTAM influenced teaching and learning practices in mathematics.

A total of twelve (12) pre-service teachers were purposefully selected for the FGD based on their ability to actively contribute to the discussion and provide meaningful perspectives. The selection criteria included: (1) active participation in UCTAM sessions, (2) demonstrated engagement with computational thinking activities, (3) willingness to share personal experiences and insights, and (4) representation of diverse academic performance levels. This selection process ensured a range of viewpoints, enriching the quality of the data collected. To guide the discussion, an interview protocol was developed, drawing on a comprehensive review of relevant literature. The FGD focused on pre-service teachers' understanding of UCTAM and its impact on their learning experiences. Pre-service teachers reflected on how the activities fostered their engagement with mathematics, enhanced their problem-solving skills, and increased their motivation to learn.

Additionally, the discussion explored how UCTAM contributed to the development of computational thinking skills such as abstraction, decomposition, pattern recognition, and algorithmic thinking. Pre-service teachers also highlighted the collaborative nature

of the activities, emphasising their role in promoting teamwork and deepening their understanding of mathematical concepts.

The discussion also focused on challenges encountered during the implementation of UCTAM. Pre-service teachers identified several barriers, including limited class time, which restricted the integration of UCTAM activities into lessons. There were concerns about aligning UCTAM with the existing mathematics curriculum and pedagogical practices. Furthermore, pre-service teachers noted resource constraints, such as insufficient access to materials and tools, which hindered the effective implementation of the approach. Detailed findings from the FGD are presented in the results section, with the interview protocol included in Appendix D.

3.8 Piloting the Instruments

Piloting the instruments was essential to ensure their validity, reliability, and alignment with the research objectives. Draft versions of the UCTSMT, questionnaire, and focus group discussion guide were developed based on a thorough literature review. These instruments were then reviewed by the researcher's supervisors, who provided detailed feedback regarding their clarity, relevance, and coherence.

For example, an initial questionnaire item, "Do you think UCTAM is effective in learning mathematics?" was considered overly general. It was revised to: "Engaging in UCTAM has improved my problem-solving skills in mathematics." Similarly, a vague item assessing confidence was rephrased from "Rate your confidence in computational thinking ability" to "I feel confident integrating UCTAM into my future mathematics lessons."

In the UCTMST, the original item, “How many squares can you see in the diagram?” was revised to: “Study the shape below and determine the total number of squares you can see in the entire shape,” aligning it more closely with the curriculum.

The revised instruments were piloted over five weeks with 15 Level 200 pre-service teachers offering Primary Education at St. Francis College of Education, Hohoe. Participants were selected for their ability to offer diverse feedback and were excluded from the main study sample to avoid bias. Feedback was collected through written reflections and informal discussions and was used to make final refinements to the instruments.

During the pilot phase, PSTs first completed the UCTMST as a pre-test to assess their initial computational thinking skills. They were then engaged in a series of unplugged computational thinking activities directly tied to the UCTAM framework, designed to enhance skills in decomposition, pattern recognition, abstraction, and algorithmic thinking. Two lessons were conducted each week.

In week 1, the focus was on decomposition. PSTs practised the “Squares Count Challenge,” where they counted the number of distinct squares in a complex geometric diagram. This task was directly linked to the combinatorial geometry topic in the college mathematics curriculum, teaching them how to break down complex figures into simpler components to analyse spatial relationships and enhance problem-solving skills.

A sample of the decomposition task is shown in Figure 5 below.

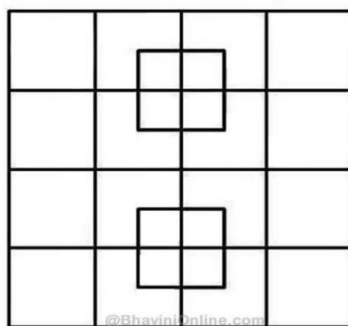


Figure 5: Squares Count Challenge

Numerous decomposition tasks were practised, with a sample task shown below. During this time, the pre-service teacher learned to break down complex problems into smaller, more manageable parts, enhancing their problem-solving skills.

In week 2, the activities centred on pattern recognition, aligned with the number theory section of the CoE mathematics curriculum. Pre-service teachers worked with sequences of triangular, square, and pentagonal numbers, practising the identification of underlying patterns and predicting subsequent numbers based on these sequences.

In week 3, the emphasis shifted to abstraction, a key concept in the CoE mathematics curriculum. Pre-service teachers engaged in tasks that required them to identify the essential details needed to solve a problem while disregarding irrelevant information.

In week 4, PSTs focused on algorithmic thinking, which is a fundamental aspect of the CoE mathematics curriculum, particularly in discrete mathematics. They were guided through exercises that required the development of step-by-step solutions to problems.

In week 5, a post-test similar to the pre-test (UCTSMT) was administered to assess learning outcomes in the PSTS' computational thinking skills. The result was compared to the pre-test results and analysis to see improvements in CT skills.

After the post-test, 12 PSTs were invited for a focus group discussion. The FGDs probed deeper into the perceived effectiveness of the UCTAM, the clarity of instructional materials, and suggestions for improvement. Qualitative data on their perceptions of the unplugged computational thinking activities, their experiences with the activities, and their challenges were collected through the FGDs

Data collected from the pilot study were analysed using both quantitative and qualitative methods. The pre- and post-test results were compared to measure improvements in computational thinking skills, using statistical tests, such as independent sample t-tests, used to assess significant differences in scores. Qualitative data from the FGD were analysed using inductive thematic analysis.

3.9 Validity and Reliability

Validity refers to the extent to which an instrument measures what it is intended to measure, while reliability concerns the consistency and stability of measurement results across time and items (Hirose & Creswell, 2023). Establishing both validity and reliability was essential to ensure that the data collected in this study were credible, trustworthy, and suitable for addressing the research objectives.

3.9.1 Validity

For the UCTMST, items were adapted from online educational resources such as CS Unplugged.com and Pinterest.com. The items were selected based on their pedagogical validity and alignment with established computational thinking frameworks to ensure that the test accurately measured the intended skills. Content validity was further ensured by aligning the items with the study objectives and the computational thinking constructs of decomposition, pattern recognition, abstraction, and algorithmic thinking.

Additionally, the items were reviewed by supervisors and PhD colleagues to confirm their clarity, relevance, and alignment with theoretical frameworks. Test administration conditions were standardised to minimise potential bias and ensure a valid assessment of participants' computational thinking abilities.

For the questionnaire, Construct validity was ensured by adapting the motivation construct and corresponding questionnaire items from established studies on unplugged computational thinking activities, including Brackmann et al. (2017), Looi et al. (2018), Sun et al. (2021), and Tsortanidou et al. (2023). This ensured that the items measured theoretically grounded and empirically supported dimensions of motivation relevant to the study.

Content validity was established through expert review by supervisors and PhD colleagues, who assessed each item for clarity, relevance, and alignment with the research objectives. Feedback from the review guided the revision of ambiguous or misaligned items, enhancing the instrument's clarity, relevance, and overall quality.

3.9.2 Reliability

The internal consistency of both instruments was assessed using Cronbach's alpha, and the results are presented in Table 2.

Table 2: Reliability Analysis for Test and Questionnaire Instruments

Instrument	Number of Items	Reliability Coefficient	Value
UCTMST	8	Cronbach's α	0.85
Questionnaire	10	Cronbach's α	0.92

For the UCTMST, Cronbach's alpha was 0.85, indicating high internal consistency among test items and suggesting reliable measurement of computational thinking constructs. For the questionnaire, Cronbach's alpha was 0.92, indicating excellent internal consistency and demonstrating that the items consistently captured pre-service teachers' perceptions and experiences regarding unplugged computational thinking activities.

3.10 Trustworthiness

The researcher applied strategies throughout the qualitative data collection process to ensure the trustworthiness of the qualitative data. These strategies aimed to enhance the credibility, confirmability, transferability, and dependability of the results regarding pre-service teachers' perceptions and challenges with Unplugged Computational Thinking Activities in Mathematics (UCTAM). The study adopts Lincoln and Guba's (1985) framework for ensuring qualitative rigour, which includes credibility, confirmability, transferability, and dependability.

3.10.1 Credibility

The researcher established credibility by engaging in prolonged interactions with the pre-service teachers to build trust and rapport. According to Shenton (2004), prolonged engagement strengthens the researcher's familiarity with the study participants, allowing for richer data collection. The prolonged engagement facilitated a deeper understanding of the pre-service teachers' perspectives, as it allowed the researcher to gather richer data about their UCTAM experiences. The researcher also fostered an open and comfortable environment for the pre-service teachers, making them feel at ease during the focus group discussion. This ensured that the data collected was both authentic and reflective of their true views.

In addition, the researcher employed member checking after the focus group discussion to ensure the accuracy of the data. Creswell and Miller (2000) emphasise that member checking is one of the most effective strategies for establishing credibility in qualitative research, as it allows participants to validate the accuracy of the collected data and interpretations. A summary of the preliminary results was shared with the pre-service teachers, and the researcher encouraged them to review and provide feedback on the accuracy of their responses. According to Creswell and Miller, this process helps identify potential misrepresentations and ensures that findings truly reflect participants' perspectives. This iterative process allowed the pre-service teachers to correct any misunderstandings and contributed to refining the final results. The researcher ensured that pre-service teachers' feedback represented their experiences, enhancing the credibility of the study.

3.10.2 Confirmability

The researcher maintained a detailed audit trail, documented every step of the data collection and analysis process. Lincoln and Guba (1985) emphasised that maintaining an audit trail enhances confirmability by providing a systematic record of research decisions, allowing for external verification. The researcher recorded the focus group discussion (FGD) and decisions made in coding and interpreting the data. The researcher ensured that a transparent and traceable record could be independently verified, enhancing confirmability.

The researcher implemented member checking by inviting pre-service teachers to review and validate their responses. After the FGD, the pre-service teachers were given opportunities to confirm the accuracy of their statements and perspectives. Lincoln and Guba (1985) assert that member checking is a crucial technique for confirmability, as

it allows participants to verify and refine the researcher's interpretations, reducing potential misrepresentations. This step addressed any potential misinterpretations, ensuring that the results represented the pre-service teachers' viewpoints.

The researcher cross-referenced field notes with audio recordings to verify the accuracy of the data. This ensured that all responses from the pre-service teachers were accurately captured and included in the analysis.

The researcher engaged in regular peer debriefing sessions with supervisors, PhD colleagues, and qualitative research experts. Lincoln and Guba (1985) highlight that peer debriefing strengthens confirmability by subjecting the researcher's interpretations to external scrutiny, helping to uncover biases and refine themes. The researcher discussed the coding process, emergent themes, and their alignment with computational thinking frameworks. Peer debriefing, as recommended by Lincoln and Guba (1985), was used to enhance confirmability by exposing the researcher's interpretations to external scrutiny, minimising personal biases. The researcher incorporated feedback from experts to refine the analysis and confirm that the themes authentically represented the data.

3.10.3 Transferability

The researcher ensures the transferability of the study by providing a detailed description of the pre-service teachers' backgrounds, which includes their levels of mathematical knowledge, prior experience with computational thinking, and demographic characteristics. Merriam (1998) asserts that rich, contextual descriptions of participants allow researchers to determine the applicability of findings to similar populations, thereby enhancing transferability. This enables other researchers to assess

whether the results can be applied to other groups of pre-service teachers with comparable educational experiences and backgrounds.

In addition, the researcher ensures methodological transparency by providing a comprehensive description of the Focus Group Discussion (FGD) process in Appendix D, following guidelines from Tracy (2010), who emphasised thick description as a key element of transferability. Tracy (2010) states that thick descriptions provide sufficient detail for readers to determine whether findings can be transferred to their contexts, thus strengthening the study's applicability.

3.10.4 Dependability

The researcher adopted Braun and Clarke's (2006) inductive thematic analysis framework to examine the qualitative data from the focus group discussion with pre-service teachers. The discussion focused on the perceptions and challenges of employing Unplugged Computational Thinking Activities in Mathematics (UCTAM). Braun and Clarke (2006) describe thematic analysis as a flexible yet rigorous method for identifying, analysing, and reporting patterns within qualitative data, making it suitable for exploring complex educational experiences. Thematic analysis was chosen for its methodological rigour and flexibility, enabling the systematic identification of patterns across diverse qualitative data sets.

The researcher engaged with the data through iterative readings of the transcripts to understand the challenges and successes reported by pre-service teachers. Initial coding was applied to identify data segments, and themes were developed, refined, and synthesised to capture the core aspects of these mathematical experiences.

The researcher ensured dependability by systematically documenting the coding process, theme development, and analysis decisions, allowing for future replication of the study. Nowell et al. (2017) emphasise that maintaining a clear audit trail of coding and theme development enhances the dependability and trustworthiness of qualitative research. This process enhances dependability by providing a replicable framework for analysing perceptions and challenges of UCTAM.

3.11 Data Collection Procedure

The data collection process employed four instruments: the Unplugged Computational Thinking Mathematics Skills Test (UCTMST), observation notes, a questionnaire, and a focus group discussion (FGD).

The UCTMST was administered to PSTs to collect quantitative data for research questions one and two. UCTMST was administered before and after the intervention. The pre-test established the baseline skills, and the post-test measured the changes after the intervention. A total of 87 pre-service teachers (PSTs) took the test. Each test was completed within one hour in a controlled classroom environment. Participants' test scripts were scored using assessment rubrics (See Appendix A). The test data was recorded and stored for analysis.

In addition to the UCTMST, the researcher used observation to collect data on PSTs. The observation notes captured how the experimental group approached problem-solving, the strategies they employed, their level of engagement, and the affective qualities exhibited throughout the UCTAM experiment. Observations were recorded at the beginning, middle, and final weeks of the intervention. The purpose of the observations was to provide complementary qualitative data that explains the

quantitative findings of research question two (2), the differences in performance between the two groups.

A structured questionnaire was also administered to collect quantitative data for research question three on PSTs' perceptions of the effectiveness of UCTAM in learning mathematics. The questionnaire assessed PSTs' experiences in terms of engagement, problem-solving, and collaboration during the intervention. It required participants to evaluate how effectively UCTAM had enhanced their mathematical understanding, creativity, and critical thinking. The questionnaires were distributed to the 44 PSTs in the experimental group immediately after the UCTAM session, under standardised instructions. After a 30-minute completion period, the researcher collected the completed questionnaires, which were then securely stored and later analysed.

In addition, the researcher conducted a Focus Group Discussion (FGD) to collect qualitative data to address research questions three (3) and four (4) on the effectiveness and challenges of UCTAM. Out of the 44 PSTs in the experimental group, 25 participants voluntarily agreed to participate in the interviews. From this group, 12 PSTs were purposively selected based on their active involvement in UCTAM, their ability to articulate experiences, and their willingness to engage in an in-depth discussion. These 12 PSTs were grouped into three subgroups of four for the FGDs. Each discussion session was held in a controlled setting and lasted for 45 minutes. FGDs were guided by an interview protocol that focused on key areas of UCTAM, such as engagement with mathematics, enhancement of problem-solving skills, development of computational thinking, collaborative skills, and challenges in learning mathematics through the UCTAM approach. The FGD sessions were audio-recorded with PSTs'

consent and transcribed verbatim, then analysed using inductive thematic analysis to identify recurring themes.

3.12 Data Analysis Procedure

Both quantitative and qualitative data were obtained from the instruments. The quantitative data consisted of pre- and post-test scores and closed-ended items on the questionnaire. The qualitative data came from the structured observation checklists and the transcripts of the Focus Group Discussions (FGD). Descriptive and inferential statistics were used for the quantitative data. Descriptive statistics (such as means, standard deviations, and percentages) helped to summarise the PSTs' performance across CT skill components, while inferential statistics (including independent samples t-tests) were used to determine whether there were significant differences between the control and experimental groups.

For the qualitative data, inductive thematic analysis was employed. This method was chosen because it allowed for the identification of patterns, categories, and themes emerging directly from the data, providing rich insights into the PSTs' experiences and perceptions. Thematic analysis was considered more appropriate than content or narrative analysis in this context, as the focus was on capturing recurring ideas and explanations rather than quantifying frequencies (as in content analysis) or constructing coherent individual stories (as in narrative analysis).

After the pre-test, the scripts were marked using the marking scheme (see Appendix B), and the PSTs' scores were entered into a spreadsheet program for analysis. Since the total scores for the CT skills components varied, decomposition (22), pattern recognition (10), abstraction (10), and algorithmic thinking (16), the scores were first converted into percentages before being used to compute the CT skills component

scores. These scores were then used to determine the PSTs' CT skill levels, based on the criteria adapted from Bloom's Taxonomy of cognitive skills (Anderson & Krathwohl, 2001) as below:

- Scores below 40% were categorised as Emerging (Remembering & Understanding), PSTs at this level demonstrated basic recall of computational thinking concepts but struggled with deeper comprehension.
- Scores from 40% to 69% were categorised as Developing (Applying & Analysing). PSTs could apply and analyse computational thinking concepts in some contexts, but lacked full mastery at this level.
- Scores of 70% and above were categorised as Proficient (Evaluating & Creating). PSTs at this level effectively synthesised and evaluated computational thinking concepts, demonstrating advanced problem-solving skills.

The PSTs' performances on the tests were described using descriptive statistics, including the mean, standard deviation, minimum, and maximum values. The data met the assumptions for parametric tests, and the researcher tested for normality by calculating skewness and kurtosis values. Normality was assumed.

The effect of UCTAM on computational thinking skills was assessed through independent and paired t-tests, comparing pre-test and post-test scores across the four components.

Subsequently, a 95% confidence interval for the mean difference between the pre-test and post-test scores was calculated to estimate the range in which the true mean difference lies. The paired t-test provided a t-statistic and p-value, revealing whether the differences between pre-test and post-test scores were statistically significant.

Additionally, Cohen's d effect size was calculated to measure the magnitude of the intervention's impact. Following Cohen (1988), effect sizes were interpreted as follows: values around 0.2 indicated a small effect, values around 0.5 represented a moderate effect, and values above 0.8 suggested a large effect. Values greater than 0.5 indicated a moderate to large effect, confirming the impact of UCTAM on computational thinking skills.

The researcher also analysed responses from the closed-ended questionnaire administered to 44 pre-service teachers in the experimental group. Descriptive statistics, including frequencies, percentages, and means, were calculated to summarise the responses and provide an overview of the PSTs' perceptions regarding the effectiveness of UCTAM. Confidence intervals were calculated for the mean scores at a 95% level, ensuring that the estimated perception scores captured the likely range of true mean values.

Qualitative data were collected from a focus group discussion with 12 pre-service teachers to explore the challenges faced while using UCTAM in mathematics learning. Inductive thematic analysis was employed to identify themes or patterns in the responses, categorising common challenges such as conceptual difficulties and instructional barriers. Direct quotes from participants were included as supporting evidence, aligning with Lincoln and Guba's (1985) recommendations for trustworthiness in qualitative research.

3.13 Data Assumptions

Prior to conducting parametric tests such as the independent and paired samples t -test, the key statistical assumptions were tested to ensure the validity of the results. These

assumptions include normality of the difference scores, absence of outliers, and homogeneity of variances.

Normality

Table 3 shows the detailed results of the normality analysis, including skewness, kurtosis, and Shapiro-Wilk test values for the UCTMST and the questionnaire scores.

Table 3: Normality Analysis for UCTMST and Questionnaire Scores

Instrument	Sample Size (n)	Skewness (SE)	Kurtosis	Shapiro-Wilk W	p-value
UCTMST Pre-test	87	-0.13 (0.26)	-0.74	0.98	0.27
UCTMST Post-test	87	-0.28 (0.26)	-0.59	0.97	0.18
Questionnaire	43	0.35 (0.26)	-1.10	–	–

From Table 3, the results of the Shapiro-Wilk test showed that the UCTMST pre-test scores were not significantly different from a normal distribution, $W(87) = 0.98$, $p = 0.27$. Similarly, the post-test scores were also normally distributed, $W(87) = 0.97$, $p = 0.18$. Skewness and kurtosis values for both the pre-test (skewness = -0.13, kurtosis = -0.74) and post-test (skewness = -0.28, kurtosis = -0.59) were within the acceptable range of ± 1 , indicating a normal distribution of scores. For the questionnaire data, the skewness (0.35) and kurtosis (-1.10) also fell within acceptable ranges, suggesting approximate normality. These suggest that the assumption of normality was satisfied for both the pre-test, post-test, and questionnaire data

Figure 6 further supports the assumption of normality through visual inspection of the histogram and boxplot of the difference scores (post-test minus pre-test). The histogram

shows a roughly symmetric bell-shaped distribution, and the boxplot shows no extreme outliers.

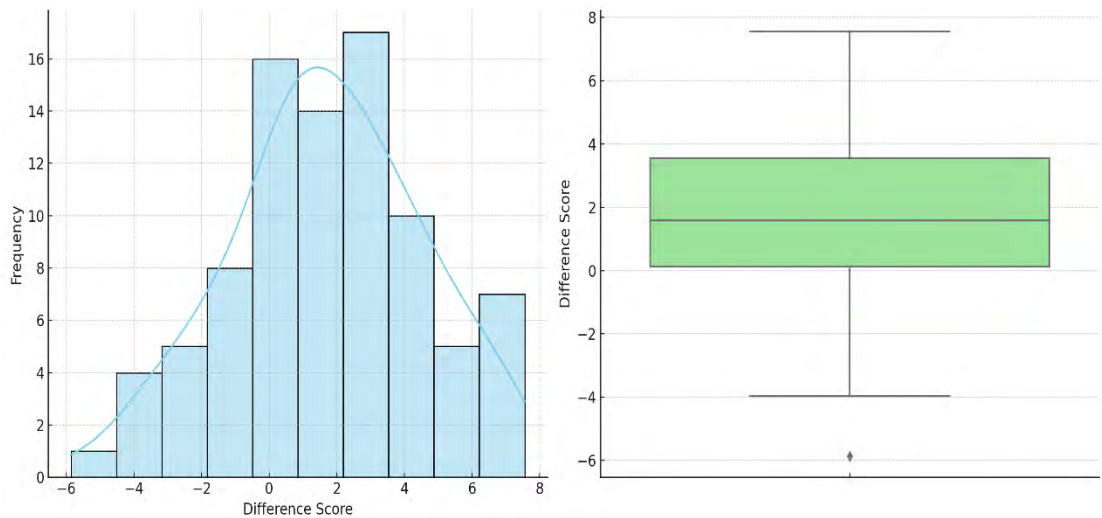


Figure 6: Visual inspection of the histogram and boxplot

Outliers

Visual inspection of the boxplot (Figure 2) revealed no extreme outliers in the distribution of the difference scores, satisfying the assumption of no influential data points that could distort the results.

Homogeneity of Variance

Levene's test was conducted to examine the assumption of homogeneity of variances between the pre-test and post-test scores.

Table 4: Levene's Test for Homogeneity of Variance

Comparison	Levene's F	p-value
Pre-test vs Post-test	0.62	0.44

The result, shown in Table 4, indicated that the assumption was met, $F = 0.62$, $p = 0.44$.

All statistical assumptions necessary for performing a paired samples t-test were met. The data were approximately normally distributed, showed no significant outliers, and exhibited equal variances. Therefore, parametric tests were deemed appropriate for further inferential analysis.

3.13 Ethical Considerations

The study adhered to ethical standards to prioritise the rights, dignity, and well-being of pre-service teachers throughout the research process. Written informed consent was obtained from all pre-service teachers before their participation. The consent form included detailed information about the study's objectives, procedures, potential benefits, and any risks involved. Pre-service teachers were fully informed about their right to withdraw from the study at any point without facing any negative consequences. The consent process ensured that pre-service teachers understood the nature of their participation and had the opportunity to ask questions or seek clarification on any concerns they had. All consent forms were stored securely and separately from the data to ensure confidentiality.

Pre-service teachers' responses were anonymised using unique identification codes. Personally identifiable information was excluded from analysis and reporting. Data were securely stored on password-protected and encrypted devices, and access was restricted to the researcher and authorised personnel bound by confidentiality agreements. The data retention policy ensured that all collected data were securely archived for the duration specified, after which they were permanently deleted to eliminate the risk of unauthorised access.

A comprehensive risk assessment was conducted to ensure that no pre-service teacher experienced undue stress or discomfort during the study. Study materials were designed to be culturally sensitive, relevant to the educational backgrounds of the pre-service teachers, and inclusive of diverse perspectives. Additionally, pre-service teachers were reminded of their right to withdraw from the study at any stage, and they were allowed to provide feedback on the study's impact on them. Pre-service teachers also had access to a summary of the study's findings, reinforcing the collaborative and respectful nature of the research. This feedback was provided in a format that allowed for further discussion and clarification, ensuring that pre-service teachers felt their voices were heard.

3.14 Summary of the Chapter

Chapter Three described the methodological framework of the study based on the pragmatic paradigm and an explanatory sequential mixed-methods design. The study involved 87 Level 200 pre-service teachers from two Colleges of Education in Ghana, selected through intact classes using purposive and convenience sampling. The intervention lasted eight weeks, with the experimental group taught using UCTAM and the control group using traditional instruction. Data were collected using the UCTMST, observation guide, questionnaire, and focus group discussion. Quantitative data were analysed using descriptive and inferential statistics, while qualitative data were analysed through inductive thematic analysis with ethical procedures observed.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

The study aimed to assess the effects of Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' levels of computational thinking skills. Data were collected from pre-service teachers (PSTs) using four research instruments: the Unplugged Computational Thinking Mathematics Skills Test (UCTMST), an observation guide, a closed-ended questionnaire, and a focus group discussion (FGD). These instruments generated both quantitative and qualitative data. The quantitative data were organised and analysed using descriptive statistics (percentages, mean, and standard deviation) and inferential statistics, specifically independent and paired-samples t-tests, to address the first four research questions outlined in Chapter One. The qualitative data obtained from the focus group discussion were analysed using inductive thematic analysis to address the fifth research question. The results are displayed in tables, figures, and graphs, and the research questions are discussed. The results of the analysis are presented and discussed in this chapter, beginning with the demographic characteristics of the PSTs.

4.1 Demographic Characteristics of Pre-service Teachers

The study explored the demographic characteristics of the pre-service teachers. Data on participants' age, gender, and specialisation were collected from 87 pre-service teachers and are presented in Table 5.

Table 5: Demographic Characteristics of the Pre-service Teachers

Category	Subcategory	Frequency (%)
<i>Age Distribution</i>		
	18–21 years	27 (31.0%)
	22–25 years	30 (34.5%)
	older than 25 years	30 (34.5%)
<i>Gender Distribution</i>		
	Male	43 (49.4%)
	Female	44 (50.6%)

Table 5 shows the sample consisted of 87 pre-service teachers, all specialising in Primary Education, and their second year of study. The age distribution of pre-service teachers was as follows: 31.0% (n = 27) were aged 18–21 years, 34.5% (n = 30) were aged 22–25 years, and another 34.5% (n = 30) were older than 25 years. The gender distribution was nearly equal, with 49.4% (n = 43) male and 50.6% (n = 44) female, which ensured diverse perspectives for analysing the effect of UCTAM.

4.2 What are the computational thinking skills proficiency levels of pre-service teachers with little or no engagement with CT activities in mathematics?

Research Question One (RQ1) aimed to assess the levels of computational thinking (CT) skills among pre-service teachers (PSTs) before the intervention. The Unplugged Computational Thinking Mathematics Skills Test (UCTMST) pre-test was administered to assess pre-service teachers' (PSTs') achievement in computational thinking (CT) across four components: decomposition, pattern recognition, abstraction, and algorithmic thinking. Each CT component had a different maximum score: decomposition (22), pattern recognition (10), abstraction (10), and algorithmic thinking

(16). Due to these variations, all raw scores were converted into percentages to enable standardised comparison across components. The conversion to percentages ensured that all CT components could be compared and interpreted on a common scale, regardless of their differing maximum scores. Table 6 shows the five-number summary of the pre-test scores, offering an overview of the score distribution and illustrated by the box plot in Figure 8 for clearer visualisation.

Table 6: Five-Number Summary and Descriptive Statistics for Pre-Service Teachers' Overall Pre-Test Percentage Scores

Statistic	Five-Number Summary				Other Statistics			
	Min	Lower Quartile	Media n	Upper Quartile	Max	Mode	Mean	Std. Dev
Pre-Test Percentage Scores	16	38	43	48	66	40	43.17	9.45

Table 6 shows the five-number summary and descriptive statistics for pre-service teachers' overall pre-test percentage scores. The minimum score was 16%, while the maximum was 66%. The interquartile range (IQR = 10%) indicates moderate dispersion, with the lower quartile (Q1) at 38% and the upper quartile (Q3) at 48%. The median score (Mdn = 43%) aligns closely with the mean (M = 43.17%) and standard deviation (SD = 9.45%). The mode (Mo = 40%) represents the most frequently occurring score among the pre-service teachers. The observed relationship, mean (43.17%) > median (43%) > mode (40%), indicates a positively skewed distribution. The rightward skew suggests that most pre-service teachers scored on the lower end, reflecting generally low performance.

For better illustration, the distribution of the pre-test scores is represented by the box plot in Figure 7 below.

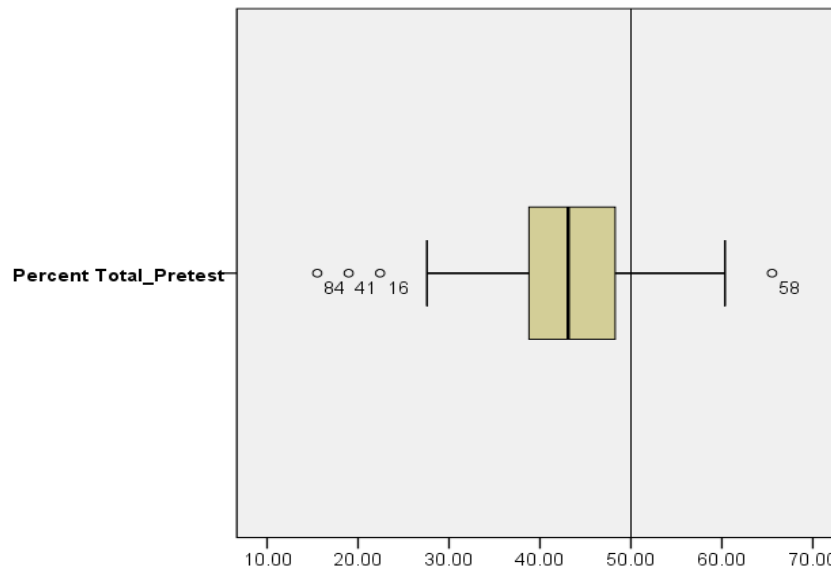


Figure 7: Box plot showing the PSTs' overall performance in the pre-test

Figure 7 provides a visual representation of the pre-test scores. The overall performance of the pre-service teachers (PSTs) in the pre-test was low, with a mean score of 43.17%. The highest score was 66%, while the lowest was 16%. The middle 50% of the PSTs scored between 38% and 48%, indicating that the majority (over 75%) obtained scores below 50% on the pre-test. Further analysis of the PSTs' achievement across the four computational thinking (CT) skill components, decomposition, pattern recognition, abstraction, and algorithmic thinking, is shown in Figure 8.

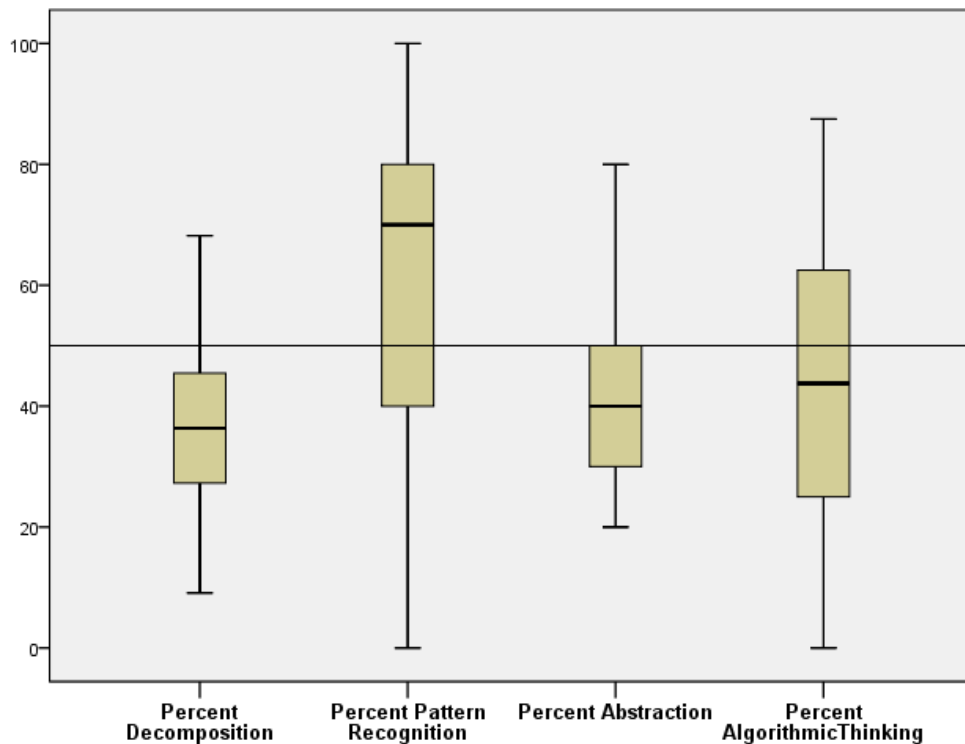
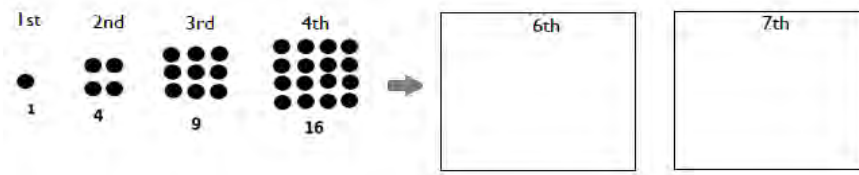


Figure 8: PSTs' Achievement in the CT skills in the Pre-test

Figure 8 shows PSTs' achievement in the CT skills (decomposition, abstraction, and algorithmic thinking) in the pre-test. PSTs' achievement in decomposition was weak, with a median score of 35% and an interquartile range (IQR) of 25% to 45%. Pattern recognition showed stronger achievement, with a median of 70% and an IQR of 40% to 80%. Abstraction had a median of 40% and an IQR of 25% to 50%. Algorithmic thinking had a median of 45%, with an IQR of 25% to 65%. These results suggest that PSTs performed better in pattern recognition compared to decomposition, abstraction, and algorithmic thinking. A detailed description of the items in pattern recognition and decomposition, highlighting the strengths and weaknesses of the PSTs, is shown in Figures 9 and 10.

- Q3a Study the pattern of dots in the diagram, and draw in the boxes provided, the sixth and seventh patterns and state the number of dots beneath each.



- Q3b How many dots will be in the will be in the 10th pattern if the pattern is extended?
- Q4a Study the pattern of squares and circles in the diagram, and draw in the boxes provided, the fifth and sixth patterns.

Figure 9: Sample of the Test Item in the Pattern Recognition CT Skills Category

Figure 9 shows a sample of the test item in the pattern recognition CT skills category. The middle 50% of the pre-service teachers (PSTs) scored between 40% and 80%, indicating that the majority (over 75%) scored above 40% in pattern recognition in the pre-test. The modal score was 70%, and while four PSTs (4.60%) achieved the highest score for the pattern recognition category, 11 PSTs (12.60%) scored zero. The PSTs' weakest performance was in the decomposition and abstraction categories. The majority (over 75%) of PSTs obtained scores below 50% in decomposition in the pre-test. Figure 10 shows a sample of the test item in the decomposition CT skills category.

- Q2 Study the shape below and determine the total number of triangles you can see in the entire shape.

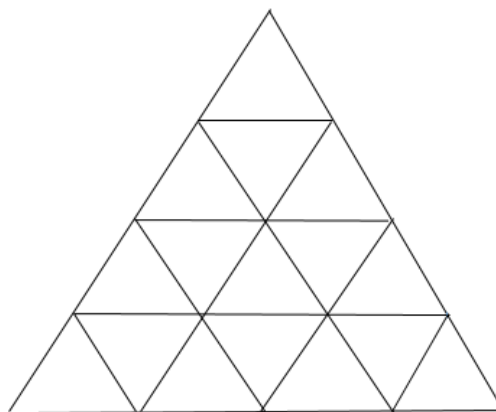


Figure 10: Sample of the test item in the decomposition CT skills category

Figure 10 involves PSTs recognizing: (i) the most obvious triangles, which are the small equilateral triangles with sides measuring $1 \times 1 \times 1$, and the large equilateral triangle with sides measuring $4 \times 4 \times 4$; and (ii) the hidden triangles, which include equilateral triangles with side lengths of $2 \times 2 \times 2$ and $3 \times 3 \times 3$. In total, there are 25 triangles: 16 small ($1 \times 1 \times 1$) triangles, 1 large ($4 \times 4 \times 4$) triangle, 5 medium ($2 \times 2 \times 2$) triangles, and 3 ($3 \times 3 \times 3$) triangles.

The scores obtained by the PSTs were used to compute their CT skills proficiency levels using Anderson and Krathwohl's (2001) criteria on page 3.12. Table 7 shows the number and percentage of PSTs who reached each of the three CT skills proficiency levels in the CT components, based on their responses to the pre-test questions.

Table 7: Number (N) and Percentage (%) of PSTs Reaching the Three CT Skills Proficiency Levels in each of the CT Components at the Pre-Test

CT skills components	Emerging	Developing	Proficient
	N (%)	N (%)	N (%)
All	35 (40)	52 (60)	0(0)
Decomposition	51 (59)	36 (41)	0(0)
Pattern Recognition	18 (21)	21 (24)	48 (55)
Abstraction	34 (39)	46 (53)	7(8)
Algorithmic Thinking	40 (46)	35 (40)	12 (14)

Table 7 shows the distribution of pre-service teachers (PSTs) across the three levels of proficiency in each computational thinking (CT) skills component. For overall CT skills, 40% of PSTs were at the emerging level and 60% at the developing level, with none reaching the proficient level.

In the decomposition component, 59% of PSTs were at the emerging level and 41% at the developing level. For pattern recognition, 21% were emerging, 24% developing,

and 55% proficient, indicating a relative strength in this area. In abstraction, 39% were emerging and 53% developing, while 8% reached proficient. In algorithmic thinking, 46% were emerging, 40% developing, and 14% reached proficiency. Additionally, Table 8 further presents the proportions of pre-service teachers (PSTs) at the emerging and developing levels of CT skills in the pre-test.

Table 8: Proportion of PSTs in Control and Experimental Groups Reaching Emerging and Developing CT skills levels before the Experiment

Group	Overall Pretest CT skills levels			Total
	Emerging	Developing	Proficient	
Control	19 (44)	24 (56)	0(0)	43 (100)
Experimental	16 (36)	28 (64)	0(0)	44 (100)
Total	35 (40)	52 (60)	0(0)	87 (100)

Table 8 shows the distribution of pre-service teachers (PSTs) in the control and experimental groups based on their computational thinking (CT) skill levels before the experiment. The results show that PSTs were proficient at two levels: emerging and developing, with none of them reaching the proficient level at this stage. In the control group, 19, representing 44% of the PSTs, were at the emerging level, while 24 (56%) were at the developing CT skill level. Similarly, in the experimental group, 16 (36%) of the PSTs were at the emerging level, whereas 28 (64%) were at the developing level. Overall, when both groups were combined, 35 PSTs (40%) were at the emerging level, while 52 (60%) were at the developing level. These results show that, before the experiment, the majority of PSTs exhibited that they were at the developing CT skill level, none reaching the proficient level.

The data was further subjected to an independent *t*-test to test the null hypothesis that ‘there is no statistically significant difference between the pre-test performance of the control and experimental groups before the experiment. The result of the *t*-test is presented in Table 9.

Table 9: Independent Samples *t*-Test Comparing Pre-Test Scores of Control and Experimental Groups

Group	n	Mean	Std. Dev.	Std. Error	<i>t</i>	Df	Sig. (2-tailed)	Cohen’s <i>d</i>
Control	43	42.16	8.58	1.31	-0.99	85	0.33	0.20
Experimental	44	44.34	9.34	1.41				

Table 9 shows the results of an independent samples *t*-test comparing the pre-test scores of the control group ($n = 43$) and the experimental group ($n = 44$). The control group scored ($M = 42.16$, $SD = 8.58$), while the experimental group scored ($M = 44.34$, $SD = 9.34$). The difference in means was not statistically significant, $t(85) = -0.99$, $p = 0.33$. Since $p = 0.33$ is greater than the alpha level of 0.05, the null hypothesis was retained, indicating no significant difference in the pre-test performance between the groups. This suggests that both groups had comparable computational thinking skills at the outset. Cohen’s $d = 0.20$ indicates a small effect size, reinforcing that the initial difference between groups was minimal. This supports the internal validity of the study by confirming that any changes observed in post-test results can be attributed to the intervention rather than pre-existing differences.

4.3 What are the post-intervention computational thinking skills proficiency levels of pre-service teachers?

Research Question 2 (RQ2) examined the post-intervention computational thinking (CT) skills proficiency levels of pre-service teachers (PSTs). The Unplugged Computational Thinking Mathematics Skills Test (UCTMST) post-test was administered to assess PSTs' achievement in CT across four components: decomposition, pattern recognition, abstraction, and algorithmic thinking. Each CT component had a different maximum score: decomposition (22), pattern recognition (10), abstraction (10), and algorithmic thinking (16).

Due to these variations, all raw scores were converted into percentages to allow for standardised comparison across components. This conversion ensured that all CT components could be compared and interpreted on a common scale, regardless of their differing maximum scores. Table 10 shows the five-number summary of the post-test scores, offering an overview of the score distribution, which is further illustrated by the box plot in Figure 12 for clearer visualisation.

Table 10: Five-Number Summary and Descriptive Statistics for Overall Post-Test Scores

Statistic	Five-Number Summary				Other Statistics			
	Min	Lower Quartile	Median	Upper Quartile	Max	Mode	Mean	Std. Dev
Overall Post-Test Scores	26	62	71	83	97	83	68.15	13.09

Table 10 shows the five-number summary and additional descriptive statistics for the overall post-test percentage scores. The minimum score was 26%, and the maximum was 97%. The interquartile range (IQR = 21%) indicates moderate dispersion, with the

lower quartile (Q1) at 62% and the upper quartile (Q3) at 83%. The median score (Mdn = 71%) closely aligns with the mean ($M = 68.15\%$, $SD = 13.09\%$). The mode ($M_o = 83\%$) represents the most frequently occurring score among the pre-service teachers. The observed relationship among the scores mean (68.15%) < median (71%) < mode (83%) indicates a negatively skewed distribution. The negative skew implies that most pre-service teachers performed well, with relatively few scoring lower. For better visualisation, the distribution of the post-test scores is illustrated by the box plot against the pre-test in Figure 11 below.

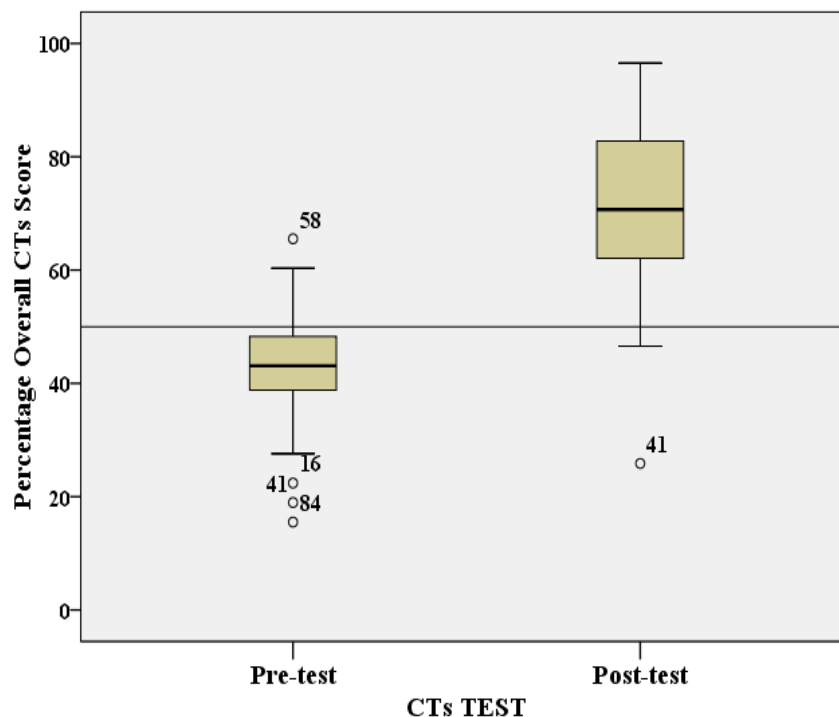


Figure 11: Box Plot Comparing PSTs Overall Percentage Post-Test Scores

Figure 11 shows the distribution of post-test scores in overall computational thinking (CT) skills. The post-test scores show an improvement, with a median score of 71% and the scores range from 41% to 97%. The middle 50% of PSTs scored between 66% and 79%, which shows that most PSTs performed above average after the UCTAM intervention. A detailed breakdown of performance across the four CT components:

decomposition, pattern recognition, abstraction, and algorithmic thinking, is provided in Figure 12.

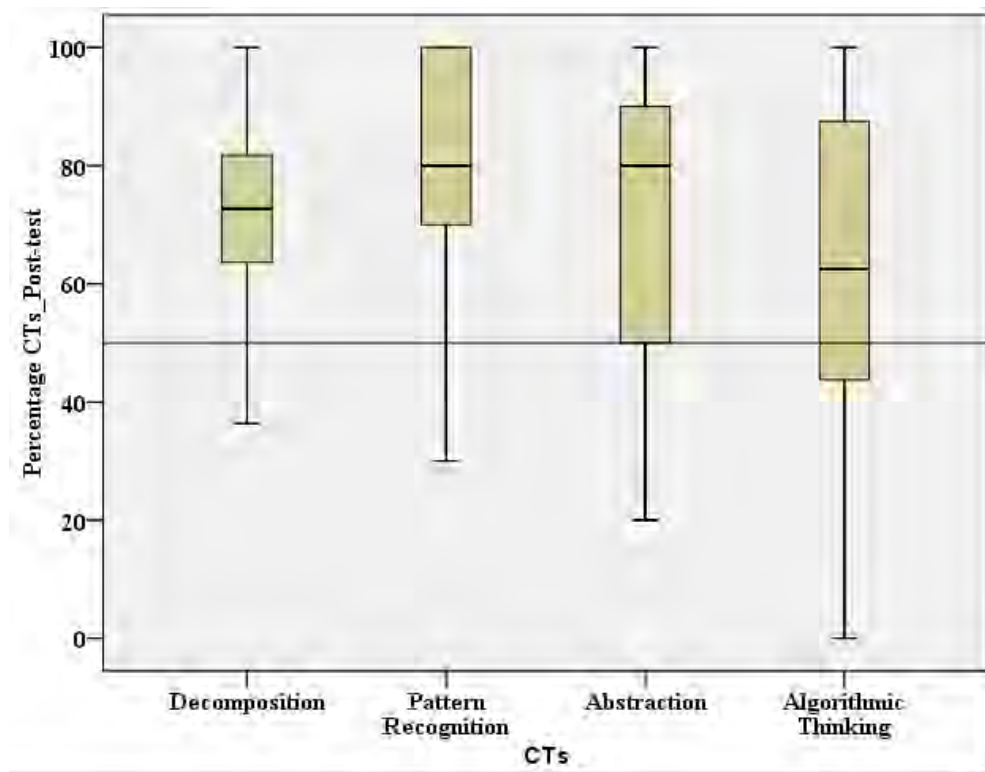


Figure 12: PSTs' Achievement in the CT Skills in the Post-test

Figure 12 shows PSTs' achievement in the CT skills: decomposition, pattern recognition, abstraction, and algorithmic thinking in the post-test. Decomposition showed improved achievement, with a median score of approximately 75% and an interquartile range (IQR) of about 65% to 85%. Pattern recognition had the highest achievement, with a median of around 85% and an IQR ranging from 70% to 100%. Abstraction also showed high achievement, with a median of approximately 80% and an IQR of 55% to 95%. Algorithmic thinking, although improved, had the lowest median score of around 65%, with a wider IQR of roughly 45% to 90%, indicating more variability in achievement among PSTs in this component.

These results suggest that PSTs performed better in pattern recognition compared to decomposition, abstraction, and algorithmic thinking. A detailed description of the items in pattern recognition and decomposition, highlighting the strengths of the PSTs, is shown in Figure 13.

Q3. Study the pattern of dots in the diagram, and draw in the boxes provided, the sixth and seventh patterns and state the number of dots under each.

The diagram shows a sequence of four triangular patterns of dots. The first pattern (1st) consists of 1 dot. The second pattern (2nd) consists of 3 dots arranged in two rows (1 on top, 2 on bottom). The third pattern (3rd) consists of 6 dots arranged in three rows (1, 2, 1). The fourth pattern (4th) consists of 10 dots arranged in four rows (1, 2, 3, 1). Below each pattern is its corresponding number: 1, 3, 6, and 10. An arrow points from the fourth pattern to two empty boxes labeled '6th' and '7th' for drawing the next patterns.

Figure 13: Sample of the Test item in the Best CT skills Component

Pattern recognition emerged as a strength among pre-service teachers (PSTs) in the post-test, with the middle 50% of scores ranging from 70% to 90% and a median of approximately 80%. This reflects a strong understanding of pattern recognition concepts among the majority of PSTs. Decomposition also showed notable improvement compared to the pre-test. In the post-test, the middle 50% scored between 60% and 100%, with a high median score, indicating a strong ability to break down complex mathematics problems into subunits. The majority of PSTs achieved scores above 70%, demonstrating substantial progress and the effectiveness of the UCTAM instructional intervention in enhancing decomposition skills. Figure 14 shows a sample of a test item in the decomposition CT skills category.

- Q1. Examine the shape below, decompose it into smaller sections, and determine the total number of squares you can see in the entire shape.

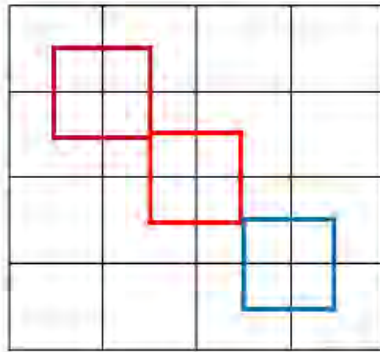


Figure 14: Sample of the Test Item in the Decomposition CT skills Category

Although the items in the decomposition category seem difficult, PSTs demonstrated exceptional critical and creative thinking skills. Through careful analysis of the diagram, they effortlessly identified the most apparent squares, including the small 1x1 unit squares and the large 8x8 unit squares. With thoughtful observation, they also uncovered the hidden squares, such as the 2x2, 4x4, and 6x6 unit squares. Altogether, there are 45 square units, consisting of 12 (1x1) squares, 19 (2x2) squares, 9 (4x4) squares, 4 (6x6) squares, and 1 (8x8) square.

The post-test scores obtained by the PSTs were used to compute their CT skills proficiency levels using the criterion indicated in Section 3.10.3. Table 11 shows the number (and in parentheses, the percentage) of the PSTs reaching the three levels of proficiency on all or each of the CT skills components.

Table 11: Number and Percentage of PSTs Reaching the Three Levels of Proficiency on All CT Skills Components

Type of CT skills	Emerging	Developing	Proficient
All	1(1%)	48(55%)	38(44%)
Decomposition	1(1%)	50(58%)	36(41%)
Pattern Recognition	1(1%)	24(28%)	62(71%)
Abstraction	4(5%)	39(45%)	44(51%)
Algorithmic Thinking	21(24%)	31(36%)	35(40%)

Table 11 shows the post-intervention proficiency levels of pre-service teachers (PSTs) across computational thinking (CT) skills. Overall, 55% of PSTs were at the developing level, 44% reached the proficient level, and only 1% remained at the emerging level. Decomposition showed progress, with 58% of PSTs at the developing level, 41% achieving proficiency, and only 1% remaining at the emerging level. Pattern recognition emerged as the strongest area, with 71% of PSTs reaching proficiency, 28% at the developing level, and only 1% remained at the emerging level, indicating a solid understanding of this pattern recognition CT skill. Similarly, abstraction demonstrated improvement, with 51% attaining proficiency, 45% at the developing level and only 5% remained at the emerging level. On the other hand, algorithmic thinking posed the greatest challenge; 40% of PSTs achieved proficiency, 36% of PSTs were at the developing level, and 24% of PSTs remained at the emerging level.

Despite this, the results reveal overall improvements in CT skills, as most PSTs transitioned from emerging level to developing and proficient categories. The UCTAM instructional intervention effectively strengthened PSTs' computational thinking, particularly in pattern recognition, abstraction, and decomposition. Table 4.8 presents

the proportion of PSTs who were at the emerging and developing levels before the intervention and their corresponding levels in the post-test.

Table 12: Proportion of PSTs in Control and Experimental Groups Reaching Emerging and Developing CT Skills Levels after the Experiment

Group	Overall Posttest CT skills levels			Total
	Emerging	Developing	Proficient	
Control	1 (2)	36 (82)	7 (16)	43 (100)
Experimental	0 (0)	2 (5)	41 (95)	44 (100)
Total	1 (1)	38 (44)	48 (55)	87 (100)

Table 12 shows the proportion of pre-service teachers (PSTs) in the control and experimental groups who reached the emerging, developing, and proficient levels of computational thinking (CT) skills after the experiment. In the control group, 2% of PSTs were at the emerging level, 82% were at the developing level, and 16% reached the proficient level in the post-test. This indicates that while most PSTs in the control group remained at the developing level, only a small proportion progressed to proficiency.

In the experimental group, none of the PSTs were at the emerging level after the intervention. Only 5% remained at the developing level, while a substantial 95% achieved proficiency in their CT skills. This shows a significant improvement in the experimental group compared to the control group.

Overall, across both groups, 1% of PSTs were at the emerging level, 44% at the developing level, and 55% reached proficiency after the intervention. These results reflect the effectiveness of the intervention, particularly in the experimental group,

where almost all PSTs progressed to the proficient level, demonstrating enhanced computational thinking skills following the implementation of Unplugged Computational Thinking Activities in Mathematics. Figure 16 shows a bar graph that visually represents the proportion of PSTs at each CT skills proficiency level (Emerging, Developing, and Proficient) before and after the experiment for both the control and experimental groups.

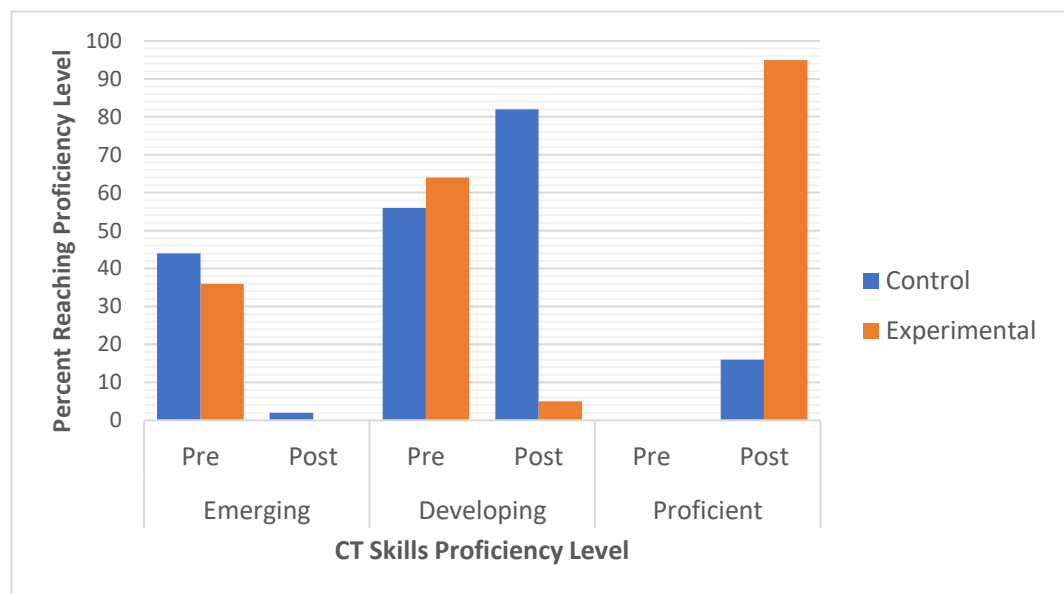


Figure 15: CT Skills Proficiency Level

From figure 15, before the intervention, the proportion of PSTs at the emerging level was higher in the control group (44%) than in the experimental group (36%). After the intervention, this proportion reduced significantly to 2% in the control group and 0% in the experimental group, illustrating a notable reduction in emerging-level PSTs, especially in the experimental group.

In terms of developing-level proficiency, 56% of PSTs in the control group and 64% in the experimental group were at this level before the experiment. Post-test results show an increase in the control group, with 82% reaching the developing level, whereas the

experimental group demonstrated a significant shift, with only 5% remaining at this level.

The most striking difference is observed at the proficient level. Before the intervention, no PSTs in either group reached proficiency. However, after the intervention, 16% of PSTs in the control group and 95% in the experimental group attained proficiency. This increase underscores the effectiveness of the experimental intervention in enhancing PSTs' CT skills, as the experimental group showed substantially greater gains in reaching the proficient level compared to the control group.

4.4 What is the effect of unplugged computational thinking activities in mathematics (UCTAM) on pre-service teachers' computational thinking skills proficiency levels? (RQ3)

Research Question 3 examined the effect of the Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' (PSTs) proficiency levels in computational thinking (CT) skills. An independent samples t-test was initially conducted to compare the pre-test scores of the control and experimental groups, which helped establish baseline equivalence. A second independent samples t-test was conducted to compare the post-test scores of both groups, providing evidence of the impact of the UCTAM intervention. Paired samples t-test was then used to assess within-group differences between pre-test and post-test scores for both the control and experimental groups. The analysis involved both between-group and within-group comparisons to evaluate the effectiveness of the intervention. An alpha level of .05 served as the threshold for determining statistical significance. The results of the independent and paired samples t-test are presented in Tables 13 and 14.

Table 13: Independent Sample T-test Results for Pre- and Post-Test Scores

	Group	N	Mean	Std. Dev.	Std. Error	T	df	Sig. (2-tailed)	Cohen's d
Pre-test	Control	43	42.16	8.58	1.31	-0.99	85	0.33	0.20
	Experimental	44	44.34	9.34	1.41				
Post-test	Control	43	61.28	8.76	1.34	-12.72	85	0.00	2.70
	Experimental	44	82.07	6.49	0.98				

Table 13 shows the results of independent samples *t*-tests comparing computational thinking (CT) skills proficiency between the control and experimental groups at both the pre-test and post-test stages. At the pre-test stage, the control group had ($M = 42.16$, $SD = 8.58$) and the experimental group ($M = 44.34$, $SD = 9.34$), $t(85) = -0.99$, $p = 0.33$, $d = 0.20$. There was no statistically significant difference between the groups. The small effect size confirms that the groups were comparable at baseline.

At the post-test stage, the experimental group ($M = 82.07$, $SD = 6.49$) scored significantly higher than the control group ($M = 61.28$, $SD = 8.76$), $t(85) = -12.72$, $p < 0.05$, $d = 2.70$. The large effect size suggests a substantial impact of the Unplugged Computational Thinking Activities in Mathematics (UCTAM) on CT skills. These results support the effectiveness of the intervention in enhancing pre-service teachers' proficiency in computational thinking. Results of the paired samples *t*-tests are reported in Table 14.

Table 14: Paired Samples *t*-Test Results for Pre- and Post-Test Scores on Overall Computational Thinking Skills

Group	Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		T	df	Sig. (2-tailed)	Cohen's <i>d</i>
				Lower	Upper				
Control	19.12	19.13	2.92	13.24	24.99	6.55	42	0.00	1.00
Experimental	37.73	16.36	2.47	32.75	42.71	15.28	43	0.00	2.31

As shown in Table 14, the results of the paired-samples *t*-test indicate statistically significant improvements in overall computational thinking skills for both the control ($n = 43$) and experimental ($n = 44$) groups. For the control group, the mean difference between post-test and pre-test scores was 19.12 (SD = 19.13), $t(42) = 6.55$, $p < 0.05$, with a 95% confidence interval (CI) of [13.24, 24.99]. Cohen's *d* was 1.00, indicating a large effect size.

The experimental group demonstrated a larger mean difference of 37.73 (SD = 16.36), $t(43) = 15.28$, $p < 0.05$, with a 95% CI of [32.75, 42.71]. Cohen's *d* was 2.31, suggesting a very large effect and indicating that the impact of the Unplugged Computational Thinking Activities in Mathematics (UCTAM) intervention was greater for the experimental group compared to the control group.

However, the experimental group showed a larger mean difference (37.73 vs. 19.12) and a higher effect size (Cohen's $d = 2.31$) compared to the control group (Cohen's $d = 1.00$). The 95% confidence intervals for the control group [13.24, 24.99] and the experimental group [32.75, 42.71] did not overlap, providing additional evidence of a meaningful difference between groups.

Based on the results, the null hypothesis (H_{01}), which stated that there is no statistically significant difference in the computational thinking skills proficiency levels of pre-service teachers taught using Unplugged Computational Thinking Activities in Mathematics (UCTAM) and those taught using the traditional instructional approach, is rejected. This supports the alternative hypothesis (H_{a1}), which stated that there is a statistically significant difference in the computational thinking skills proficiency levels of pre-service teachers taught using Unplugged Computational Thinking Activities in Mathematics (UCTAM) and those taught using the traditional instructional approach.

4.4.1 Effect of the UCTAM on PST Achievement in the various CT Skill components

The section examines the effects of the Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' (PSTs) achievement across four computational thinking (CT) skill components. The results presented in the tables below highlight how PSTs performed in each skill area in the pre-test and post-test.

4.4.2 Effect of UCTAM on Pre-Service Teachers' Decomposition Skills

The section presents the results of both independent samples and paired samples t-tests conducted to test the second hypothesis “ H_{02} : There is no statistically significant difference in the decomposition skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach”. An independent samples t-test was first conducted to compare the pre-test scores of the control group and the experimental group to determine baseline equivalence. A second independent samples t-test compared their post-test scores to assess the impact of the intervention. In addition, paired samples t-tests were used to examine within-group differences between pre-test and post-test scores for each group. An alpha level of 0.05

was adopted for determining statistical significance. The results are presented in Tables 15 and 16.

Table 15: Independent Sample T-Test Results for Pre- and Post-Test Scores on Decomposition Tasks

	Group	N	Mean	Std. Dev.	Std. Error	t	df	Sig. (2-tailed)	Cohen's d
Pre-test	Control	43	33.77	10.65	1.62	0.89	85	0.37	0.31
	Experimental	44	31.04	11.82	1.78				
Post-test	Control	43	69.53	13.04	1.99	-3.88	85	0.00	0.80
	Experimental	44	79.05	11.77	1.77				

Table 15 shows the results of an independent samples *t*-test conducted to compare the pre-test and post-test performance of the control and experimental groups in decomposition skills. At pre-test, the control group ($M = 33.77$, $SD = 10.65$) and the experimental group ($M = 31.04$, $SD = 11.82$) did not differ significantly, $t(85) = 0.89$, $p = 0.37$, indicating the groups were comparable at baseline. A small effect size ($d = 0.31$) further supports the minimal difference in decomposition skills before the intervention.

Following the intervention, the control group had ($M = 69.53$, $SD = 13.04$) and the experimental group had ($M = 79.05$, $SD = 11.77$), $t(85) = -3.88$, $p < 0.05$. The effect size was moderate ($d = 0.80$), indicating that the experimental group, which received UCTAM-based instruction, outperformed the control group in decomposition skills. Differences in decomposition task achievement within each group were examined using a paired samples *t*-test. The results are presented in Table 16.

Table 16: Paired Sample T-test Results for Pre- and Post-Test Scores on Decomposition Tasks

Group	Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)	Cohen's d
				Lower	Upper				
Control	35.76	15.05	2.30	30.88	40.16	15.55	42	0.00	1.36
Experimental	48.01	15.85	2.39	43.15	52.87	16.11	43	0.00	2.42

As shown in Table 16, the results of the paired-samples *t*-test indicate statistically significant improvements in decomposition skills for both the control ($n = 43$) and experimental ($n = 44$) groups. For the control group, the mean difference between post-test and pre-test scores was 35.76 (SD = 15.05), $t(42) = 15.55$, $p < 0.05$, with a 95% confidence interval (CI) of [30.88, 40.16]. Cohen's *d* was 1.36, indicating a large effect size.

The experimental group demonstrated a greater mean difference of 48.01 (SD = 15.85), $t(43) = 16.11$, $p < 0.05$, with a 95% CI of [43.15, 52.87]. Cohen's *d* was 2.42, suggesting a very large effect and indicating that the Unplugged Computational Thinking Activities in Mathematics (UCTAM) intervention had a stronger impact on enhancing decomposition skills than the traditional instructional approach.

The experimental group showed both a larger mean gain (48.01 vs. 35.76) and a higher effect size ($d = 2.42$ vs. $d = 1.36$) compared to the control group. The 95% confidence intervals for the control group [30.88, 40.16] and the experimental group [43.15, 52.87] do not overlap, offering additional evidence of a meaningful difference between the two groups.

Based on these results, the null hypothesis (H_{02}), which states that there is no statistically significant difference in the decomposition skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach, is rejected. Therefore, the alternative hypothesis (H_{a2}), which states that there is a statistically significant difference in the decomposition skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach, is accepted.

4.4.3 Effect of UCTAM on Pre-Service Teachers' Pattern Recognition Skills

The section presents the results of both independent samples and paired samples t-tests conducted to test the third hypothesis concerning the effect of the Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' (PSTs) pattern recognition skills. An independent samples t-test was first conducted to compare the pre-test scores of the control group and the experimental group to determine baseline equivalence. A second independent samples t-test compared their post-test scores to assess the impact of the intervention. In addition, paired samples t-tests were used to examine within-group differences between pre-test and post-test scores for each group. An alpha level of 0.05 was adopted for determining statistical significance. The results are presented in Tables 17 and 18.

Table 17: Independent Sample T-test Results for Pre- and Post-Test Scores on Pattern Recognition Tasks

	Group	N	Mean	Std. Dev.	Std. Error	T	df	Sig. (2-tailed)	Cohen's d
Pre-test	Control	43	58.06	30.62	4.67	0.64	85	0.53	0.13
	Experimental	44	54.11	28.37	4.28				
Post-test	Control	43	76.45	21.19	3.23	-3.36	85	0.00	0.70
	Experimental	44	88.32	13.46	2.03				

Table 17 shows the results of an independent t-test comparing the pre-test and post-test scores of the control and experimental groups in computational thinking (CT) skills, specifically pattern recognition. For the pre-test, the control group ($M = 58.06$, $SD = 30.62$) and the experimental group ($M = 54.11$, $SD = 28.37$) showed no statistically significant difference in their pattern recognition skills, $t(85) = 0.64$, $p = 0.53$, with a negligible effect size (Cohen's $d = 0.13$), indicating that both groups had similar baseline levels in pattern recognition.

However, in the post-test, the control group ($M = 76.45$, $SD = 21.19$) scored significantly lower than the experimental group ($M = 88.32$, $SD = 13.46$). The independent t-test revealed a statistically significant difference between the two groups, $t(70.88) = -3.36$, $p < 0.05$, with a moderate effect size ($d = 0.70$). This indicates that the experimental group experienced greater improvement in pattern recognition skills compared to the control group. To examine the differences in Pattern recognition tasks within the groups, a paired sample t-test was conducted. The results are presented in Table 18.

Table 18: Paired Sample T-test Results for Pre- and Post-Test Scores on Pattern Recognition Tasks

Group	Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)	Cohen's d
				Lower	Upper				
Control	18.39	26.86	4.09	10.38	26.40	4.50	42	0.00	0.70
Experimental	34.21	31.51	4.75	24.90	43.52	7.32	43	0.00	1.10

As shown in Table 18, the results of the paired-samples *t*-test indicate statistically significant improvements in pattern recognition skills for both the control ($n = 43$) and experimental ($n = 44$) groups. For the control group, the mean difference between post-test and pre-test scores was 18.39 ($SD = 26.86$), $t(42) = 4.50$, $p < 0.05$, with a 95% confidence interval (CI) of [10.38, 26.40]. Cohen's *d* was 0.70, indicating a medium effect size.

The experimental group demonstrated a greater mean difference of 34.21 ($SD = 31.51$), $t(43) = 7.32$, $p < 0.05$, with a 95% CI of [24.90, 43.52]. Cohen's *d* was 1.10, suggesting a large effect and indicating that the Unplugged Computational Thinking Activities in Mathematics (UCTAM) intervention had a stronger impact on enhancing pattern recognition skills than the traditional instructional approach.

The experimental group showed both a larger mean gain (34.21 vs. 18.39) and a higher effect size ($d = 1.10$ vs. $d = 0.70$) compared to the control group. The 95% confidence intervals for the control group [10.38, 26.40] and the experimental group [24.90, 43.52] do not overlap, further supporting the observed difference.

Based on these results, the null hypothesis (H_{03}), which states that there is no statistically significant difference in the pattern recognition skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach, is rejected. Therefore, the alternative hypothesis (H_{a3}), which states that there is a statistically significant difference in the pattern recognition skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach, is accepted.

4.4.4 Effect of UCTAM on Pre-Service Teachers' Abstraction Skills

The section presents the results of both independent samples and paired samples t-tests conducted to test the fourth hypothesis concerning the effect of the Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' (PSTs) abstraction skills. An independent samples t-test was first conducted to compare the pre-test scores of the control group and the experimental group to determine baseline equivalence. A second independent samples t-test compared their post-test scores to assess the impact of the intervention. In addition, paired samples t-tests were used to examine within-group differences between pre-test and post-test scores for each group. An alpha level of 0.05 was adopted for determining statistical significance. The results are presented in Tables 19 and 20.

Table 19: Independent Sample T-test Results for Pre- and Post-Test Scores on Abstraction Skills

	Group	N	Mean	Std. Dev.	Std. Error	T	df	Sig. (2-tailed)	Cohen's d
Pre-test	Control	43	42.11	16.41	2.503	0.55	85	0.58	-0.10
	Experimental	44	40.43	15.17	2.287				
Post-test	Control	43	56.08	18.28	2.787	-8.33	85	0.00	1.80
	Experimental	44	86.33	15.28	2.304				

Table 19 shows the results of an independent t-test comparing the pre-test and post-test scores of the control and experimental groups in computational thinking (CT) skills, specifically abstraction. For the pre-test, the control group ($M = 42.11$, $SD = 16.41$) and the experimental group ($M = 40.43$, $SD = 15.17$) showed no statistically significant difference in their abstraction skills, $t(85) = 0.55$, $p = 0.58$. The result suggests that both groups had similar baseline abilities in abstraction before the intervention.

However, in the post-test, the control group ($M = 56.08$, $SD = 18.28$) scored significantly lower than the experimental group ($M = 86.33$, $SD = 15.28$). The independent t-test revealed a statistically significant difference between the two groups, $t(85) = -8.33$, $p < 0.05$, with a large effect size ($d = 1.80$). This indicates that the experimental group experienced substantially greater improvement in abstraction skills compared to the control group. To examine the differences in abstraction tasks within the groups, a paired samples t-test was conducted. The results are presented in Table 20.

Table 20: Paired Sample T-test Results for Pre- and Post-Test Scores on Abstraction Tasks

Group	Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)	Cohen's d
				Lower	Upper				
Control	13.97	26.83	4.09	5.96	21.98	3.41	42	0.00	0.50
Experimental	45.90	22.08	3.32	39.39	52.41	13.8	43	0.00	2.10

As shown in Table 20, the results of the paired-samples t-test indicate statistically significant improvements in abstraction skills for both the control and experimental groups. For the control group, the mean difference between post-test and pre-test scores was 13.97 (SD = 26.83), $t(42) = 3.41$, $p < 0.05$, with a 95% confidence interval (CI) of [5.96, 21.98]. Cohen's d was 0.50, indicating a medium effect size.

The experimental group demonstrated a substantially larger improvement, with a mean difference of 45.90 (SD = 22.08), $t(43) = 13.80$, $p < 0.05$, and a 95% CI of [39.39, 52.41]. Cohen's d was 2.10, indicating a very large effect size and suggesting that the Unplugged Computational Thinking Activities in Mathematics (UCTAM) intervention had a stronger impact on enhancing abstraction skills compared to the traditional method.

The experimental group showed a larger mean gain (45.90 vs. 13.97) and a higher effect size ($d = 2.10$ vs. $d = 0.50$) than the control group. The non-overlapping 95% confidence intervals for the control group [5.96, 21.98] and the experimental group [39.39, 52.41] provide additional support for the greater effectiveness of the UCTAM intervention in enhancing abstraction skills.

Based on these results, the null hypothesis (H_{04}), which states that there is no statistically significant difference in the abstraction skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach, is rejected. Therefore, the alternative hypothesis (H_{a4}), which states that there is a statistically significant difference in the abstraction skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach, is accepted.

4.4.4 Effect of UCTAM on Pre-Service Teachers' Algorithmic Thinking Skills

The section presents the results of both independent samples and paired samples t-tests conducted to test the fifth hypothesis concerning the effect of the Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' (PSTs) algorithmic thinking skills. An independent samples t-test was first conducted to compare the pre-test scores of the control group and the experimental group to determine baseline equivalence. A second independent samples t-test compared their post-test scores to assess the impact of the intervention. In addition, paired samples t-tests were used to examine within-group differences between pre-test and post-test scores for each group. An alpha level of 0.05 was adopted for determining statistical significance. The results are presented in Tables 21 and 22.

Table 21: Independent Sample T-Test Results for Pre- and Post-Test Scores on Algorithmic Thinking Tasks

	Group	N	Mean	Std. Dev.	Std. Error	T	df	Sig. (2-tailed)	Cohen's d
Pre-test	Control	43	45.05	21.26	3.24				
	Experimental	44	43.01	22.34	3.36	-0.06	85	0.96	0.09
Post-test	Control	43	63.89	20.32	3.09				
	Experimental	44	79.11	12.82	1.93	-9.61	85	0.00	2.10

Table 21 presents the results of independent-samples *t*-tests comparing the pre-test and post-test scores of the control and experimental groups on algorithmic thinking tasks. In the pre-test, the control group ($M = 45.05$, $SD = 21.26$) and the experimental group ($M = 43.01$, $SD = 22.34$) did not differ significantly, $t(85) = -0.06$, $p = 0.96$, indicating that both groups had comparable baseline levels in algorithmic thinking before the intervention. The effect size was negligible, Cohen's $d = 0.09$, suggesting no meaningful difference at this stage.

However, in the post-test, the control group ($M = 63.89$, $SD = 20.32$) scored significantly lower than the experimental group ($M = 79.11$, $SD = 12.82$), $t(85) = -9.61$, $p < 0.05$. The effect size was very large, Cohen's $d = 2.10$, indicating that the Unplugged Computational Thinking Activities in Mathematics (UCTAM) had a substantial positive impact on algorithmic thinking skills compared to the traditional instructional method. To examine the differences in algorithmic thinking tasks within the groups, a paired sample *t*-test was conducted. The results are presented in Table 22.

Table 22: Paired Sample T-test Results for Pre- and Post-Test Scores on Algorithmic Thinking Tasks

Group	Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)	Cohen's d
				Lower	Upper				
Control	18.84	22.16	3.38	12.03	25.65	5.57	42	0.00	0.85
Experimental	36.10	24.26	3.66	28.72	43.48	9.86	43	0.00	1.40

Table 22 shows the results of paired-samples t-tests conducted to examine the effect of the Unplugged Computational Thinking Activities in Mathematics (UCTAM) on algorithmic thinking skills among pre-service teachers in both the control and experimental groups. The results of the paired-samples t-test indicate statistically significant improvements in algorithmic thinking skills for both the control ($n = 43$) and experimental ($n = 44$) groups. For the control group, the mean difference between post-test and pre-test scores was 18.84 ($SD = 22.16$), $t(42) = 5.57$, $p < 0.05$, with a 95% confidence interval (CI) of [12.03, 25.65]. Cohen's d was 0.85, indicating a moderate effect size.

The experimental group demonstrated a greater mean difference of 36.10 ($SD = 24.26$), $t(43) = 9.86$, $p < 0.05$, with a 95% CI of [28.72, 43.48]. Cohen's d was 1.49, suggesting a very large effect and indicating that the Unplugged Computational Thinking Activities in Mathematics (UCTAM) intervention had a stronger impact on enhancing algorithmic thinking skills than the traditional instructional approach.

The experimental group showed both a larger mean gain (36.10 vs. 18.84) and a higher effect size ($d = 1.49$ vs. $d = 0.85$) compared to the control group. The 95% confidence intervals for the control group [12.03, 25.65] and the experimental group [28.72, 43.48]

do not overlap, further supporting the observed difference between the two instructional methods.

Based on these results, the null hypothesis (H_{04}), which states that there is no statistically significant difference in the algorithmic thinking skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach, is rejected. Therefore, the alternative hypothesis (H_{a4}), which states that there is a statistically significant difference in algorithmic thinking skills proficiency levels of pre-service teachers taught using UCTAM and those taught using the traditional instructional approach, is accepted.

4.5 Results from Observation and FGD on the PSTs' Participation and Engagement with UCTAM

The observation notes provided qualitative insights into the experimental group's engagement with the Unplugged Computational Thinking Activities in Mathematics (UCTAM). The researcher documented how pre-service teachers solved problems, the strategies they attempted, their level of engagement, and how these evolved from the beginning through to the final weeks of the intervention. While the quantitative data captured changes in computational thinking skills through pre- and post-tests, the observation notes added depth by illustrating the nature and progression of PSTs' problem-solving behaviours over time.

Beginning Weeks of the Intervention

a) Attacking the Problems

Many PSTs exhibited uncertainty in problem-solving, particularly in decomposition and algorithmic thinking, as shown in Section 4.2. Over 75% scored below 50% on the pre-test, indicating difficulty with CT tasks. They often approached decomposition

problems holistically, leading to confusion and inefficiency. Additionally, most PSTs could not recognise repetitive sequences or mathematical patterns, instead relying on surface-level strategies, as illustrated in Exhibits 1 and 2.

B. PATTERN RECOGNITION TASKS

Exhibit 1

Q3a Study the pattern of dots in the diagram, and draw in the boxes provided, the sixth and seventh patterns and state the number of dots beneath each.

Q3b How many dots will be in the 10th pattern if the pattern is extended?

C. ABSTRACTION TASKS

Exhibit 2

Q5a The diagram below shows patterns made with match sticks. Study the pattern of sticks and determine the number of sticks that will be needed to make the tenth pattern.

Q5b What is the rule for the nth pattern?

From the observed exhibits above, many PSTs encountered difficulties identifying relationships, structures in pattern recognition and abstraction tasks, which affected their overall problem-solving strategies.

b) Strategies Used in the Problem-Solving Process

Many PSTs relied on ineffective strategies when solving mathematical tasks. They focused on surface-level observations and often misapplied pattern recognition, identifying sequences without validating underlying rules. This led to incorrect generalisations, unjustified assumptions, and errors. Rather than analysing why a pattern emerged, they extended it intuitively without critical evaluation.

c) Participation, Collaboration, and Communication

Pre-service teachers generally exhibited low participation, poor collaboration, and communication gaps. Few contributed actively to class discussions; most remained passive, hindered by uncertainty, fear of making mistakes, and low confidence in

explaining mathematical reasoning. Discussions were dominated by a few voices, and group work was largely ineffective, as many preferred working in isolation and avoided peer interaction.

d) Affective Qualities Displayed

Pre-service teachers faced various affective challenges. Many lacked confidence and became frustrated or disengaged after unsuccessful attempts. While a few showed enthusiasm and curiosity in tackling tasks, the majority demonstrated low motivation and approached activities passively.

Middle Weeks of the Intervention

a) Attacking the Problems

Through continuous exposure to UCTAM problem-solving strategies and guided practice, PSTs became more proficient in decomposing CT tasks. Their pattern recognition improved, especially in identifying number sequences and geometric formations. They shifted from guesswork to structured reasoning, adopting systematic approaches and justifying their methods with logical explanations.

b) Strategies Used in the Problem-Solving Process

Pre-service teachers used diagrams and visual tools, such as number charts, geometric sketches, and flow diagrams, to tackle pattern recognition and abstraction tasks. They applied logical reasoning and justified their choices, moving away from intuition and trial-and-error methods.

c) Participation, Collaboration, and Communication

Pre-service teachers' levels increased, with PSTs actively contributing to discussions, sharing ideas, asking questions, and seeking clarification. Collaboration also improved as PSTs worked in groups, tested solutions, explained their reasoning, and engaged with alternative perspectives from peers.

d) Affective Qualities Displayed

Pre-service teachers demonstrated greater perseverance, spending more time analysing CT problems and refining their strategies. Confidence and interest grew, with many expressing enjoyment in discovering patterns and relationships in mathematical problems.

Final Weeks of the Intervention

a) Attacking the Problems

During the final weeks of the intervention, many pre-service teachers (PSTs) exhibited structured and systematic approaches to solving problems. PST problem-solving was grounded in logical reasoning rather than guesswork, as shown in exhibits 3 and 4.

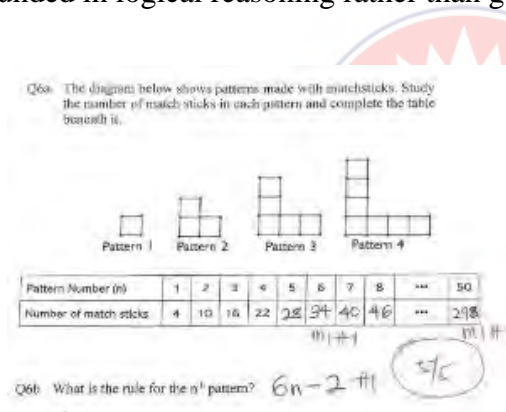


Exhibit 3

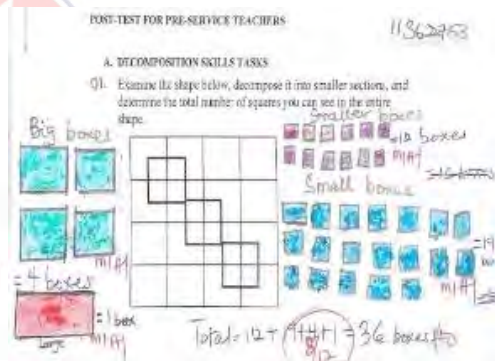


Exhibit 4

Additionally, PSTs recognised and applied abstraction techniques. PSTs demonstrated greater proficiency in developing step-by-step solutions that followed a clear logical progression.

b) Strategies Used in the Problem-Solving Process

Pre-service teachers demonstrated increased confidence and accuracy in applying effective problem-solving strategies. They drew connections between problems, recognised underlying structures, and applied learned patterns to develop logical solutions. Their approach reflected analytical thinking and reduced errors in algorithmic

reasoning. PSTs exhibited greater precision in constructing structured, efficient sequences of operations.

c) Engagement, Collaboration, and Communication

Many PSTs actively participated in problem-solving discussions, showing a strong willingness to engage with tasks, ask questions, and explore alternatives. Collaboration within groups became more effective, with members refining solutions collectively, exchanging ideas, critically analysing approaches, and offering constructive feedback. Communication improved significantly. PSTs articulated their reasoning clearly and concisely, justifying methods and demonstrating logical thought processes. They also actively listened to peers and engaged in meaningful discussions, which deepened their understanding.

d) Affective Qualities Displayed

Pre-service teachers exhibited high confidence and approached challenging tasks with assurance. They explored multiple strategies and trusted their reasoning abilities. Motivation also improved; many showed enthusiasm and curiosity, approaching tasks with resilience rather than giving up easily.

4.6 How do pre-service teachers perceive the effectiveness of unplugged CT mathematics activities in learning mathematics (RQ4)

Research question four sought to investigate how PSTs perceive the effectiveness of unplugged CT mathematics activities in learning mathematics. The objective was to examine the perception of effectiveness of the activities in improving pre-service teachers' CT skills. The researcher presented data using both descriptive statistics and inductive thematic analysis. The researcher determines the perception of the effectiveness by first dichotomising the mean ratings into two groups - high and low perception of effectiveness, using a cut-off point of 3.41 proposed by Abdelrasheed

(2018). Abdelrasheed recommended that to determine the cut-off point for dichotomising the 5-point Likert-type scale, the range of the scale is calculated by $(5 - 1 = 4)$ and then divided by five, as it is the greatest value of the scale ($4 \div 5 = 0.80$). Afterwards, number one, which is the least value in the scale, was added to identify the maximum of this cell. The length of the cells is determined below:

- From 1 to 1.80 represents (strongly disagree).
- From 1.81 until 2.60 represents (do not agree).
- From 2.61 until 3.40 represents (true to some extent).
- From 3:41 until 4:20 represents (agree).
- From 4:21 until 5:00 represents (strongly agree).

So, the upper limit of the middle range was 3.41, and dichotomised the mean ratings into being frequently practised or not. The responses meeting or exceeding this threshold of 3.41 were considered indicative of a positive perception of UCTAM. The results were used to put the respondents into high and low perceptions of effectiveness groups. Table 23 shows the mean, standard deviation (SD), number, and percentage of pre-service teachers (PSTs) who rated each item on the 5-point Likert scale.

Table 23: Pre-Service Teachers' Perception of the Effectiveness of UCTAM

Perception of the effectiveness of UCTAM	SD N(%)	D N(%)	N N(%)	A N(%)	SA N(%)	M	STD DEV
UCTAM has deepened my understanding of mathematical concepts.	3(7)	5(11)	6(14)	27(61)	3(7)	3.50	1.02
UCTAM has enhanced my creative and critical thinking skills.	2(5)	4(9)	8(18)	27(61)	3(7)	3.57	0.93
Participating in UCTAM has improved my understanding of key computational thinking skills, such as abstraction and decomposition.	6(14)	4(9)	13(29)	18(41)	3(7)	3.18	1.15
Engaging in UCTAM has improved my problem-solving skills in mathematics.	3(7)	4(9)	9(21)	23(52)	5(11)	3.52	1.05
UCTAM makes learning mathematics more engaging for me.	4(9)	4(9)	7(16)	24(55)	5(11)	3.50	1.11
My motivation to learn mathematics has increased after participating in UCTAM.	5(11)	6(14)	4(9)	20(45)	9(21)	3.50	1.29
UCTAM are easy to design and implement in the classroom.	4(9)	7(16)	8(16)	20(45)	5(11)	3.34	1.16
UCTAM has enriched my learning experience through collaborative activities with my peers.	5(11)	5(11)	2(5)	22(50)	10(23)	3.61	1.28
I feel confident integrating UCTAM into my future mathematics lessons.	5(11)	11(25)	3(7)	23(52)	2(5)	3.14	1.19
I clearly understand how to apply UCTAM in teaching mathematics.	6(14)	(11)	11(25)	18(41)	4(9)	3.20	1.19

Table 23 shows the results of PSTs' perception of the effectiveness of UCTAM in learning mathematics. The results are in two categories: high perception rating ($M \geq 3.41$) and low perception rating ($M < 3.41$).

High Perception Rating ($M \geq 3.41$)

Several items had mean scores over the cut-off in Table 4.19, as indicated in section 4.4, suggesting that UCTAM was a good approach to learning mathematics. 72% ($n = 34$) of PSTs agreed or strongly agreed to the item, "UCTAM enriched my learning experience through collaborative activities with my peers," which had a mean score of 3.61 ($SD = 1.28$). This implies that PSTs placed a high priority on UCTAM's collaborative nature. Similarly, 68% ($n = 36$) of PSTs agreed or strongly agreed that UCTAM encouraged higher-order thinking, with the statement "UCTAM enhanced my creative and critical thinking skills" having a mean score ($M = 3.57, SD = 0.93$).

The statement "Engaging in UCTAM improved my problem-solving skills in mathematics" also had a mean score of ($M = 3.52, SD = 1.05$), with 70% ($n = 35$) of PSTs agreeing or strongly agreeing with it.

Both "My motivation to learn mathematics increased after participating in UCTAM" ($M = 3.50, SD = 1.29$) and "UCTAM deepened my understanding of mathematical concepts" ($M = 3.50, SD = 1.02$) had high ratings, with 66% ($n = 33$) and 64% ($n = 32$) of PSTs, expressed positive perceptions. The mean score for the statement "UCTAM made learning mathematics more engaging" was ($M = 3.50, SD = 1.11$); 65% ($n = 32$) of PSTs agreed or strongly agreed.

Low Perception Rating ($M < 3.41$)

Table 23 shows that some items had mean scores below the cutoff, indicated areas where PSTs disagree or agree somewhat. 54% ($n = 27$) of PSTs disagreed or agreed somewhat with the statement "Participating in UCTAM improved my understanding of key computational thinking skills such as abstraction and decomposition", with a mean (3.18 , $SD = 1.15$), suggesting that although some understanding was gained, it was not very effective. In a similar vein, 58% ($n = 29$) of PSTs disagreed or agreed somewhat to the statement to the statement "UCTAM is easy to design and implement in the classroom" ($M = 3.34$, $SD = 1.16$), indicating that PSTs regarded the implementation process to be relatively challenging.

Confidence in applying UCTAM also appeared to be a concern. "I feel confident integrating UCTAM into my future mathematics lessons" had a mean score ($M = 3.14$, $SD = 1.19$), with only 48% ($n = 24$) of PSTs expressing confidence. Similarly, "I clearly understand how to apply UCTAM in teaching mathematics" had a mean score ($M = 3.20$, $SD = 1.19$), with 50% ($n = 25$) of PSTs indicating understanding.

4.7 Thematic Analysis of Pre-Service Teachers' Perception of UCTAM

Pre-service teachers' perceptions of the effectiveness of UCTAM in learning mathematics were further explored using focus group discussions (FGD). Twelve PSTs participated in the FGD, in three groups of four PSTs. The researcher used the six-phase inductive thematic analysis developed by Braun and Clarke (2006) to analyse the FGD data on PSTs' perception of the effectiveness of UCTAM in learning mathematics.

The researcher transcribed the FGDs verbatim. The transcribed data was examined multiple times and compared to the original audio recordings. The researcher repeatedly

read transcribed data to gain an in-depth understanding of PSTs' perspectives on the effectiveness of UCTAM in learning mathematics.

The researcher used the open coding approach to identify recurrent codes in PSTs' UCTAM experiences. Based on patterns found in participants' responses, the researcher categorised the generated codes into more general groups. The researcher categorised these codes into themes that represented PSTs' UCTAM experiences.

The researcher refined and validated the themes by cross-referencing them with the data. The final themes were assessed and named based on their relevance and distinctiveness. Each theme was analysed in detail and was structured to illustrate PSTs' perceptions of the effectiveness of UCTAM in learning mathematics. The inductive thematic analysis revealed six key themes representing PSTs' perception of the effectiveness of UCTAM in learning mathematics, which are detailed below.

Theme 1: Enhanced Problem-Solving Skills

This theme emerged from PSTs' responses on how UCTAM influenced their ability to solve mathematical problems. Pre-service teachers indicated that UCTAM enhanced their problem-solving skills, in logical reasoning and analytical thinking. The pre-service teachers made this clear in their responses to the question, "How effective was UCTAM in learning mathematics to you?" in the focus group discussion. Four (4) PSTs shared their experiences:

"For me, I now break math questions into sections before I start solving them, which helps me solve the math question easily," PST 1.

"I normally break math questions into parts and examine each part separately, which makes solving math questions less difficult for me," PST 3.

"I now solve math problems step by step, first decomposing the mathematics questions and looking for patterns, which makes it easier to find solutions," PST 6.

"Before, I used to struggle with math questions, but now I see how breaking them down and identifying patterns simplifies the process for me," PST 5.

Based on the PSTs' responses, UCTAM enhanced the PSTs' problem-solving skills. The UCTAM also develops PSTs' analytic and logic skills, enabling them to break down complex problems to make them easier to solve and thereby enhancing their computational efficiency.

Theme 2: Enhanced Understanding of Mathematical Concepts

This theme emerged from PSTs' responses on how engaging in UCTAM influenced their understanding of mathematical concepts. PSTs noted that UCTAM enhanced their understanding of mathematics and provided a clear and more structured approach to learning mathematics, as captured in their response to the question "How effective was UCTAM in learning mathematics to you?" in the focus group discussion. Four PSTs shared their views:

"I used to think math was just memorising formulas. After the UCTAM experiment, I realised math isn't just about formulas and getting correct answers, it's about understanding why the steps work" PST 9

"Before, I always got stuck and gave up whenever I solved a math question. Now I know how to break math questions into smaller parts, and that has made math so much clearer for me." PST 12

"The way I approached math questions was different this time. I didn't just rush to the answer; I took time to understand each step, and that made me understand the whole process." PST 5

"Previously, I just learned rules and memorised the formulas, but I now understand that math is a step-by-step process." PSTs 6

From the PSTs' responses, the UCTAM changed their perspective of the problem as an ensured step-by-step process that goes beyond getting the right answers. It helped PSTs develop a structured understanding of what solving mathematical problems entails.

Theme3: Enhanced Motivation

A third theme that emerged from the FGDs was enhanced motivation. PSTs expressed a renewed interest and enthusiasm for mathematics, attributing this shift to the interactive and engaging nature of the UCTAM. They expressed this view in responding to the question, "How effective was UCTAM in learning mathematics to you?" in the focus group discussion. Three (3) PSTs in the group expressed their views:

"I used to find math a bit dull, but now I see it as a practical and exciting subject, because of the practical questions we normally solve during UCTAM class. I love the challenge of identifying patterns and algorithms together whenever I am solving any math question." PSTs 1

"Previously, I didn't ask questions during math class, but now I feel encouraged to ask questions to clear my doubts and explore more. UCTAM made me curious and helped me take part in the class" PST 10

"Working with my friends now to solve math problems has made me enjoy learning math and given me confidence in math, compared to previously, when I used to solve math problems alone. UCTAM made math more fun and easier to understand "PST 7

From the PSTs' responses, the UCTAM boosted PSTs' motivation to learn mathematics by making it more engaging, practical, and enjoyable for them to work collaboratively.

Theme 4: Enhanced Confidence in Mathematical Problem-Solving

This theme emerged from the views shared by PSTs regarding their participation in UCTAM. PSTs revealed that UCTAM enhanced their self-confidence in solving mathematics problems. PSTs reported an increase in confidence after participating in UCTAM. The pre-service teachers made this clear in their responses to the question, "How effective was UCTAM in learning mathematics to you?" in the focus group discussion. Three PSTs shared their views:

" Previously, I didn't have any belief in myself that I could solve math questions correctly, but now, I feel more assured that I can tackle math problems without fear of getting the wrong answers" PST 2

"I used to solve math assignments alone, without consulting my classmates when I encountered difficulties. With UCTAM, I have realised that sharing ideas and math solutions is the best. This made me feel more capable in my ability and boosted my confidence in solving math questions. Also, I feel less intimidated by the difficult math questions" PST 4

"Now my classmates and I normally analyse and solve math assignments after school, compared to the first time that we didn't work together, I gained a lot of confidence in myself in approaching the math assignment questions " PST 9

From the PSTs' responses, the UCTAM enhanced the PSTs' confidence in solving mathematical problems. UCTAM's collaborative and interactive approach to solving problems enhanced the pre-service teachers' confidence. Pre-service teachers felt more capable and less daunted in solving mathematical problems through the sharing of ideas and engaging in collaborative tasks.

Theme 5: Enhancing Critical Thinking and Creativity

This theme emerged from the views shared by PSTs on how UCTAM influences their critical and creative thinking skills in mathematics. PSTs noted that UCTAM makes them analyse problems more deeply and provides innovative methods of solving mathematics problems. The pre-service teachers made this clear in their responses to the question, "How effective was UCTAM in learning mathematics to you?" in the focus group discussion. Three PSTs shared their views:

"For me, I don't rush to find answers to the math questions again. I analyse the questions critically and look for the best method that solves the questions. I do away with the wrong methods. This makes me explain the reasons behind my answers compared to the first. if the teacher asked me how I got the answer, I don't know how to explain to him how I got my answer." PST 10

Previously, I had this notion that if the formula didn't work, then the question is wrong or not solvable. But now I think outside the box to look for a solution to the questions. Sometimes my friends and I bring out new methods to solving the problem, which are different from the rest of my colleagues' own, but we all arrive at the same answers. PST 8"

"For me, I don't pay attention to the math questions whenever I am solving them. I now take time to read them well, analyse, and look for new ways of solving

them. Now, any question I come across, I spend time to critically analyse it and solve it well" PST 11

From the PSTs' responses, the UCTAM promoted critical thinking and creativity. PSTs revealed that there is a significant improvement in their critical thinking and creativity skills. PSTs expressed how UCTAM inspired them to think outside the box and develop innovative solutions to mathematics problems.

Theme 6: Enhanced Collaboration

The theme emerged from the responses of PSTs on how UCTAM impacted their collaborative learning experiences. PSTs highlighted the benefits of working in groups, valuing peer learning, and the opportunity to gain new perspectives on problem-solving. The pre-service teachers made this clear in their responses to the question, "How effective was UCTAM in learning mathematics to you?" in the focus group discussion.

Three PSTs shared their views:

"I, in particular, don't like participating in group discussion, because I fear that my colleagues will laugh at me when I give a wrong answer, but after the UCTAM, I now learned that working in groups is the best way. I now share my ideas freely with group members, and also work with them whenever any mathematics assignment is given to us" PST 1

"I usually have my solution wrong whenever I'm solving math questions, because I don't understand the procedures, and I also don't like comparing my answer with my colleagues. The group activities we performed in the classroom through the UCTAM made me realise that I have to always discuss my solution with my group members." PST 5

"After solving a math question, and I didn't get the answer, I gave up, and I didn't continue again, but now anytime I get stuck on the way, I copy the question to the group discussion, and we all solve it together. I now believe that working in groups is the best way to go" PST 8

From the PSTs' responses, the UCTAM promoted collaboration among the PSTs by providing them with the opportunity to work in groups and share ideas. The

collaborative approach not only enhanced their understanding of mathematical concepts but also made learning more engaging and effective.

4.8 What are pre-service teachers' challenges in learning mathematics through Unplugged Computational Thinking Activities in Mathematics (RQ 5)?

Research question five explored PSTs' challenges in learning mathematics through UCTAM. The objective was to identify and analyse challenges PSTs encounter in learning mathematics through UCTAM. The researcher followed Braun and Clarke's (2006) six-phase inductive thematic analysis in section 4.7 to analyse the FGD data on PSTs' challenges in learning mathematics through UCTAM. The inductive thematic analysis revealed four key themes representing PSTs' challenges encountered learning mathematics through UCTAM, which are detailed below.

Theme 7: Lack of Familiarity

This theme emerged from PSTs' responses to challenges encountered while learning mathematics through UCTAM. PSTs reported limited exposure to UCTAM. Pre-service teachers indicated that they had not encountered such activities before their involvement in the study. The pre-service teachers responded to the question, "What challenges have you encountered in learning mathematics through the UCTAM? in the focus group discussion. Two PSTs shared their views:

"The questions we normally solve during the UCTAM class are different, more practical, and difficult compared to the questions we solve in our normal class. I don't have the courage to solve the questions and how to apply them because we are not used to these questions, I struggled to see the connection between these questions and the mathematics concepts we were learning" PST 4

"For me, the questions we solve in UCTAM class are not in our textbook, although the questions make us think and analyse well, we are not used to these

questions and the approach. This method is new to all of us. Now that we are trying to adjust ourselves to it." PST 10

From the PSTs' responses, PSTs have a challenge with limited exposure to the UCTAM approach. PSTs reported a disconnection between UCTAM and the mathematics concepts they learned in the classroom. PSTs found it difficult to conceptualise the practical application of UCTAM in a way that aligns with traditional mathematics learned in the classroom.

Theme 8: Resource Constraints

The theme emerged from PSTs' responses to challenges encountered while learning mathematics through UCTAM. PSTs reported limited resources to effectively implement UCTAM. Pre-service teachers revealed that the material used during the UCTAM lessons was inadequate. The pre-service teachers responded to the question, "What challenges have you encountered in learning mathematics through the UCTAM?" in the focus group discussion. Two PSTs shared their views:

"For me, I think the material given to us to work with during the class is inadequate; the material should be provided to all of us. Sometimes I had to wait for my turn to use the materials, and it slowed me down." PST 7

"I didn't participate in most of the group work in the class, because the materials were not many materials, 1 material for 6 of us in the group. Usually, it is one or two group members who use the material, and some of us don't get access to the material. It makes participation in group activities very difficult," PST12.

From the PSTs' responses, PSTs have a challenge with limited resources available during the UCTAM class. PSTs reported they faced challenges in accessing the materials, which hindered their ability to participate in the UCTAM lesson effectively.

Theme 9: Curriculum Alignment

This theme emerged from PSTs' responses to challenges encountered while learning mathematics through UCTAM. PSTs expressed difficulty in reconciling the unplugged CT mathematics activities with the prescribed mathematics curriculum. PSTs expressed that incorporating unplugged CT mathematics activities would conflict with the curriculum syllabus. The pre-service teachers responded to the question, "What challenges have you encountered in learning mathematics through the UCTAM? in the focus group discussion. Two PSTs shared their views:

"The questions are not working for me. They're not helpful and don't relate to the math we are learning in our normal class. They're not helping me understand the math concepts. They're not related to our math curriculum,"
PST 4

"Honesty, I don't see what we are learning aligned with our curriculum. I feel like the UCTAM class is holding us back and doesn't help me learn the math topic we are supposed to learn for this semester. I found it challenging to fit these activities into the current curriculum." PST 9

From the PSTs' responses, PSTs have a challenge with curriculum alignments. PSTs reported they faced challenges with curriculum alignment. They struggled to integrate unplugged CT mathematics activities into their mathematics curriculum.

Theme 10: Time Constraints

This theme emerged from PSTs' responses to challenges encountered while learning mathematics through UCTAM. PSTs expressed time constraints as challenges encountered while learning mathematics through UCTAM. PSTs expressed that the duration was too short to allow for a full exploration of unplugged CT mathematics activities. The pre-service teachers responded to the question, "What challenges have you encountered in learning mathematics through the UCTAM? in the focus group discussion. Two PSTs shared their views:

“The questions are too difficult and time-consuming compared to our normal class. I spent too much time solving questions on UCTAM compared to the time I spent on solving math questions in a normal class. Class periods are too short for me .” PST 7

“Sometimes, one activity can take like 40 to 60 minutes, and the questions require more time before we solve them. The time given to us whenever we are to solve a problem is too short. I wish we had more time to focus on each activity” PST 2

From the PSTs' responses, PSTs have time constraints as a challenge in learning mathematics through UCTAM. PSTs reported that they struggled to fully explore these activities within the limited class periods and often felt rushed.

4.6 Discussion

The section discusses the results of the five research questions. Each research question was discussed alongside relevant findings.

Research Question One (RQ1) assessed the levels of computational thinking (CT) skills among pre-service teachers (PSTs). The five-number summary (min = 16%, max = 66%, median and mean \approx 43%, IQR = 10%) revealed generally low performance. Over 75% of PSTs scored below 50%, indicating limited computational thinking (CT) skills among pre-service teachers. The result supports findings from Delal and Oner (2020) and Mumcu et al. (2023), who report that many PSTs enter teacher education with little exposure to CT concepts and practices.

Among the CT components, pattern recognition was the most developed, with 55% of PSTs demonstrating some proficiency. This is likely due to its overlap with prior mathematical learning experiences (Merino-Armero et al., 2022). Conversely, decomposition, abstraction, and algorithmic thinking were weaker; 59% of PSTs were at the emerging level in decomposition, and only 14% showed competence in

algorithmic thinking. The result supports the findings of Delal and Oner (2020) and Mumcu et al. (2023), who reported that many pre-service teachers (PSTs) have challenges in breaking down problems, isolating relevant information, and designing structured solutions.

Kolb's Experiential Learning Theory (1984) and Papert's Constructionism (1980) explain these outcomes. Kolb asserts that cognitive skills, such as decomposition, abstraction, and algorithmic thinking, are developed through active engagement, reflection, and application. Papert similarly emphasises that computational thinking skills are developed when learners construct their own knowledge by creating, testing, and refining solutions. The low performance in these CT components reflects limited exposure to unplugged computational activities grounded in experiential and hands-on learning, which are essential for building higher-order problem-solving skills.

Research Question Two (RQ2) examined the post-intervention CT proficiency levels of pre-service teachers (PSTs). Post-test results showed improvement, with scores ranging from 26% to 97%, and the mean rose to 68.15%, median 71%, compared to the pre-test median of 43%. Scores fell within an interquartile range of 62% to 83% and a mode of 83% reflected high and consistent performance among PSTs.

Post-test results show improved CT skills among PSTs, with the highest performance in pattern recognition (85% median), followed by abstraction (80%), decomposition (75%), and algorithmic thinking (65%). These findings align with earlier studies, all of which underscore the importance of UCTAM in developing CT skills (Chan et al., 2020; Yeni et al., 2021; Polat & Yilmaz, 2022; Love et al., 2022). These findings are grounded in Kolb's Experiential Learning Theory (1984) and Papert's Constructionism (1980). Kolb emphasises learning through active engagement, reflection, and iterative

experience, principles central to unplugged CT tasks. Papert's Constructionism highlights learning through creation and tangible problem-solving. The improvement in PSTs' CT skills confirms that experiential, hands-on learning environments, such as UCTAM, foster meaningful and transferable cognitive development, particularly in complex areas like abstraction and decomposition.

Research Question Three (RQ3) examined the effect of Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' (PSTs') computational thinking (CT) proficiency levels. The results revealed that the experimental group significantly outperformed the control group across all CT components. The overall post-test mean score for the experimental group was 82.07, while the control group recorded 61.28, with a large effect size (Cohen's $d = 2.70$). For decomposition, the experimental group achieved a mean gain of 48.01 compared to 35.76 for the control group. The effect size was larger for the experimental group ($d = 2.42$) than for the control ($d = 1.36$).

In pattern recognition, the experimental group achieved a mean gain of 34.21, whereas the control group gained 18.39, with respective effect sizes of $d = 1.10$ and $d = 0.70$. For abstraction, the experimental group had a mean gain of 45.90, while the control group achieved 13.97. The effect size was $d = 2.10$ for the experimental group and $d = 0.50$ for the control. In algorithmic thinking, the experimental group gained 36.10, outperforming the control group's 18.84, with effect sizes of $d = 1.49$ and $d = 0.85$, respectively. These results are consistent with findings by Yeni et al. (2021) and Polat and Yilmaz (2022), who emphasised that unplugged CT activities enhance learners' proficiency in decomposition, pattern recognition, abstraction, and algorithmic thinking.

The observed improvements align with Papert, (1980) theory of constructionism, which asserts that learners build knowledge most effectively through hands-on, creative, and self-directed tasks. UCTAM supported this by engaging PSTs in interactive problem-solving activities that fostered meaningful knowledge construction. The findings also reflect Kolb's (1984) experiential learning theory, which emphasises learning through direct experience and reflection. The structure of UCTAM followed Kolb's learning cycle, allowing PSTs to engage in concrete tasks, reflect on them, develop abstract concepts, and apply these concepts in practice.

The observation data collected during the UCTAM intervention provided insights into how pre-service teachers (PSTs) developed their computational thinking skills over time. Initially, many PSTs struggled with decomposition and algorithmic thinking, often approaching problems as wholes rather than breaking them into parts, leading to confusion and inefficiency. Their pattern recognition skills were weak, as they focused on surface features without identifying underlying rules. These challenges align with Agbo et al. (2024), who observed that decomposition remains difficult without explicit instruction, and Chan et al. (2020), who noted that intuition-based approaches to algorithmic thinking often result in errors. Participation and collaboration were limited, as many PSTs lacked confidence and hesitated to share their reasoning.

As the intervention progressed, PSTs' approaches became more structured. They used diagrams, number charts, and flow diagrams to address decomposition, pattern recognition, and abstraction tasks systematically. Confidence and participation improved, with PSTs actively discussing ideas, asking clarifying questions, and collaborating to refine solutions. These developments reflect findings by Love et al.

(2022) and Yeni et al. (2021), who emphasised that unplugged computational thinking activities enhance systematic reasoning and learner confidence.

In the final weeks, PSTs demonstrated logical and organised problem-solving. They developed clear algorithmic solutions, communicated strategies confidently, and engaged collaboratively with increased resilience and curiosity. This aligns with Ocak et al. (2023) and Polat and Yilmaz (2022), who found that unplugged activities foster analytical thinking, structured problem-solving, and the ability to generalise concepts. Research Question Four (RQ4) explored pre-service teachers' (PSTs') perceptions of the effectiveness of Unplugged Computational Thinking Activities in Mathematics (UCTAM). Quantitative results showed generally positive perceptions. Seventy-two percent (72%) of PSTs agreed or strongly agreed that UCTAM enriched their learning experiences through collaborative tasks ($M = 3.61$, $SD = 1.28$). This theme of "*enhanced collaborative learning*" was also echoed in the focus group discussions, where PSTs emphasised that working together helped build a stronger understanding of mathematical concepts. One PST noted, "*Working with my friends now to solve math problems has made me enjoy learning math and given me confidence.*" These findings are consistent with Love et al. (2022) and Yeni et al. (2021), who highlighted the social and collaborative benefits of unplugged CT activities. The results support Kolb's (1984) Experiential Learning Theory, which emphasises learning through active, collaborative experiences that foster reflection and meaning-making.

In addition, sixty-eight percent (68%) of PSTs believed UCTAM improved their critical and creative thinking skills ($M = 3.57$, $SD = 0.93$). This aligns with the theme of *enhanced critical thinking and creativity*, which emerged from the focus group as participants shared how the activities required them to think outside the box and try

new strategies. One PST expressed, “*I don’t rush to find answers again. I analyse questions critically and look for the best method.*” These results are consistent with Agbo et al. (2024), who observed that unplugged CT activities stimulate innovative thinking.

Similarly, seventy percent (70%) of PSTs reported enhanced problem-solving abilities ($M = 3.52$, $SD = 1.05$), which ties into the theme of *improved confidence* from the focus group discussions. PSTs highlighted how the CT approach helped them break down problems and think logically. One remarked, “*I now solve math problems step by step, first decomposing questions and looking for patterns.*” These findings support Papert’s (1980) Constructionism, which posits that learners construct knowledge actively through meaningful, hands-on engagement and reflection.

Despite these positive outcomes, PSTs expressed moderate confidence in applying UCTAM to their future teaching. Only forty-eight percent (48%) felt confident integrating it into lessons ($M = 3.14$, $SD = 1.19$), and fifty percent (50%) expressed a clear understanding of its classroom application ($M = 3.20$, $SD = 1.19$). This matches the theme of *improved confidence*, where PSTs during the discussion mentioned needing more training and experience to use UCTAM effectively in their teaching practice. One PST admitted, “*I feel confident sometimes, but I still don’t fully understand how to use UCTAM in teaching.*” This aligns with Polat and Yilmaz (2022), who emphasised the importance of targeted training for CT integration.

Research Question Five (RQ5) explored the challenges pre-service teachers (PSTs) encountered while learning mathematics through Unplugged Computational Thinking Activities in Mathematics (UCTAM). Four main challenges were identified: lack of familiarity, resource constraints, curriculum misalignment, and time limitations.

PSTs expressed that UCTAM felt unfamiliar and disconnected from their usual mathematics experiences. One noted, *“The questions we solve in UCTAM are practical and difficult. I struggled to see their connection to the mathematics concepts we were learning.”* Another added, *“These questions are not in our textbook. Although they make us think, we are not used to them.”* This aligns with findings from Agbo et al. (2024) and Mumcu et al. (2023), who observed that many PSTs lack prior exposure to computational thinking approaches, making early engagement difficult. This challenge reflects Kolb’s (1984) Experiential Learning Theory, which emphasises learning through direct experience and active reflection, something difficult to achieve when the method feels unfamiliar.

Resource constraints also limited engagement. As one PST shared, *“I had to wait for my turn to use the material, and it slowed me down,”* while another said, *“Only one or two group members use the material, making participation difficult.”* These concerns are consistent with Love et al. (2022), who stressed that the absence of sufficient materials reduces learners' opportunities for meaningful interaction. This supports Papert’s (1980) Constructionism, which underscores the value of hands-on learning through tangible tools and collaborative problem-solving.

Curriculum misalignment and time constraints further hindered implementation. One PST remarked, *“These questions don’t relate to the math we are learning in class,”* and another added, *“Sometimes one activity can take 40 to 60 minutes. I wish we had more time.”* These findings support Chan et al. (2020) and Polat and Yilmaz (2022), who found that integrating computational thinking is often resisted due to poor curriculum alignment. Likewise, Ocak et al. (2023) noted that effective implementation requires sufficient instructional time. These issues also tie back to Kolb’s Experiential

Learning Theory, which emphasises the need for time to engage in the full learning cycle of doing, reflecting, and applying.



CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.0 Introduction

This chapter provides an overview of the study, presents key findings and conclusions based on the findings, and offers recommendations regarding the effect of UCTAM on the computational thinking skills of pre-service teachers.

5.1 Summary of the Study

The study examined the effect of UCTAM on PSTs' levels of computational thinking skills. The study was guided by five objectives: to assess PSTs' levels of CT skills, to evaluate the effect of UCTAM on PSTs' CT skills, to investigate PSTs' perceptions of UCTAM's effectiveness in learning mathematics, and to identify the challenges PSTs faced learning mathematics through UCTAM. The study aimed to enhance problem-solving, critical thinking, and interdisciplinary links between mathematics and computer science, and develop 21st-century skills. However, the study had limitations, including its focus on two institutions and the exclusion of digital tools, which limited the generalizability of the findings.

The literature review was organised around six major themes: theoretical review, theoretical framework, conceptual review, conceptual framework, empirical review, and gaps in the literature. The theoretical framework was founded on constructionist theory and experiential learning theory. The study developed a conceptual framework that illustrates the relationships among key variables. The empirical review focused on key CT components, such as decomposition, pattern recognition, abstraction, and algorithmic thinking, and examined how these were applied in the Ghanaian mathematics classroom through UCTAM. The literature review also explored PSTs' CT

skills and the effectiveness of UCTAM. Additionally, the review identified challenges faced by PSTs in learning mathematics through UCTAM. The chapter concluded by highlighting gaps in existing research.

A pragmatic, mixed-methods approach was employed to assess the effect of UCTAM on PSTs' CT levels. An explanatory sequential design was used, with 87 pre-service teachers selected through convenience and purposive sampling from two Colleges of Education in the Volta region. The experimental group participated in UCTAM for 8 weeks, whereas the control group received traditional teaching methods. Data collection included the Unplugged Computational Thinking Mathematics Skills Test (UCTSMT), observation, questionnaire, and focus group discussion.

Cronbach's Alpha validated the reliability of both the UCTSMT and the questionnaire; qualitative data were evaluated thematically. Data analysis included both quantitative and qualitative methods. The quantitative data were analysed using descriptive statistics (percentages, means, and standard deviations) as well as inferential statistics, especially the independent samples t-test. The results were presented in tables, figures, and graphs, and they focused on PSTs' performance levels in key CT skills. The qualitative data were thematically analysed to provide further information about the PSTs' experiences and perspectives of UCTAM.

5.2 Key Findings

Research Question 1: What is the level of computational thinking skills among pre-service teachers?

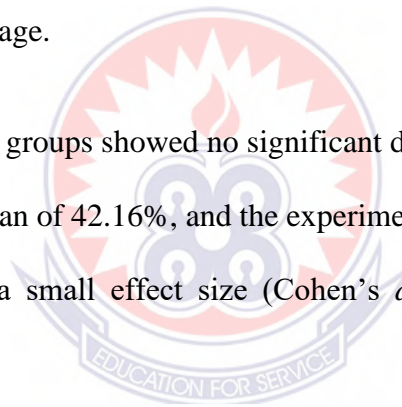
Research Question One (RQ1) assessed the pre-intervention levels of computational thinking (CT) skills among pre-service teachers (PSTs). The average pre-test score was

43.17%, with most PSTs scoring below 50%, indicating weak overall CT proficiency. The distribution was positively skewed, with scores ranging from 16% to 66%.

When disaggregated by CT components, pattern recognition was the strongest area, with a median score of 70% and 55% of PSTs reaching proficiency. In contrast, decomposition had a median of 35%, with no PSTs proficient; abstraction scored a median of 40%, with only 8% proficient; and algorithmic thinking had a median of 45%, with 14% proficiency.

In terms of overall CT proficiency, none of the PSTs reached the proficient level; 60% were developing, and 40% emerging. Decomposition remained the most difficult, with 59% at the emerging stage.

A comparison between groups showed no significant difference in pre-test scores. The control group had a mean of 42.16%, and the experimental group 44.34%, with $t(85) = -0.99$, $p = 0.33$, and a small effect size (Cohen's $d = 0.20$), confirming baseline equivalence.



Research Question 2: What is the post-intervention level of pre-service teachers' computational thinking skills?

The overall mean score was 68.15%, median 71%, and mode 83%, indicating high performance. Scores ranged from 26% to 97%, with an interquartile range (IQR) of 62% to 83%, showing a negatively skewed distribution.

Pattern recognition had the highest performance, with a median of 85% and 71% of PSTs reaching proficiency. Abstraction followed with a median of 80% and 51% proficiency. Decomposition had a median of 75% with 41% reaching proficiency. Algorithmic thinking recorded the lowest, with a median of 65% and 40% proficiency.

In total, 44% of PSTs were proficient, 55% developing, and 1% emerging. In the experimental group, 95% attained proficiency, with none at the emerging level. In contrast, only 16% of the control group reached proficiency, while 82% were developing and 2% emerging. These results highlight the effectiveness of the UCTAM intervention.

Research Question 3: What is the effect of Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' computational thinking skills?

The findings revealed no statistically significant differences in the pre-test scores between the control and experimental groups across overall computational thinking (CT) skills and the four CT components: decomposition, pattern recognition, abstraction, and algorithmic thinking. This indicates that both groups were comparable at baseline.

Following the intervention, a statistically significant difference was observed in the overall post-test scores. The experimental group outperformed the control group with a large effect size (Cohen's $d = 2.70$). Paired samples t-tests further confirmed improvements within both groups; however, the experimental group recorded a greater mean gain (37.73 vs. 19.12) and a higher effect size (2.31 vs. 1.00), demonstrating a more substantial enhancement in CT skills.

In decomposition skills, the experimental group achieved significantly higher post-test scores compared to the control group ($M = 79.05$ vs. $M = 69.53$), with a moderate effect size ($d = 0.80$). Paired comparisons showed greater improvement in the experimental group (mean gain = 48.01, $d = 2.42$) than in the control group (mean gain = 35.76, $d = 1.36$), indicating the stronger influence of the UCTAM intervention.

Similarly, the experimental group outperformed the control group in pattern recognition skills at post-test ($M = 88.32$ vs. $M = 76.45$), with a moderate effect size ($d = 0.70$). The mean gain for the experimental group was 34.21 ($d = 1.10$), while the control group recorded a smaller gain of 18.39 ($d = 0.70$), reflecting the added value of the UCTAM approach.

For abstraction skills, the post-test results showed a large and statistically significant difference between the experimental and control groups ($M = 86.33$ vs. $M = 56.08$), with a large effect size ($d = 1.80$). The experimental group also exhibited a notably larger gain (mean = 45.90, $d = 2.10$) compared to the control group (mean = 13.97, $d = 0.50$), confirming the intervention's effectiveness in enhancing abstract thinking.

Lastly, in algorithmic thinking, the experimental group again scored significantly higher than the control group in the post-test ($M = 79.11$ vs. $M = 63.89$), with a large effect size ($d = 2.10$). Paired t-tests showed a greater improvement in the experimental group (mean gain = 36.10, $d = 1.49$) than in the control group (mean gain = 18.84, $d = 0.85$), reinforcing the positive impact of UCTAM on this CT component.

Observation data further confirmed that PSTs developed systematic and logical approaches to problem-solving, enhanced confidence, and collaborative learning behaviours through UCTAM.

Research Question 4: What are pre-service teachers' perceptions of the effectiveness of UCTAM in learning mathematics?

The questionnaire findings revealed that PSTs perceived UCTAM as effective for learning mathematics, with 72% indicating it enhanced collaborative learning, 68% reporting improved creative and critical thinking skills, 70% indicating strengthened

problem-solving abilities, and 66% reporting increased motivation. However, only 48% felt confident to implement UCTAM in future teaching, and 50% understood its practical application.

Thematic analysis from focus group discussions revealed six themes: Enhanced Problem-Solving Skills, Enhanced Understanding of Mathematical Concepts, Enhanced Motivation, Enhanced Confidence in Mathematical Problem-Solving, Enhanced Critical Thinking and Creativity, and Enhanced Collaboration. These themes showed that PSTs perceived UCTAM as improving their analytical skills, conceptual understanding, motivation, confidence, creativity, and collaborative learning experiences in mathematics.

Research Question 5: What challenges did pre-service teachers face in learning mathematics through UCTAM?

The thematic analysis identified four key challenges: Lack of Familiarity, where PSTs struggled due to limited prior exposure to UCTAM; Resource Constraints, as insufficient materials hindered effective participation; Curriculum Alignment, where PSTs found difficulties integrating UCTAM with their mathematics syllabus; and Time Constraints, as class periods were too short to fully engage with UCTAM activities. These challenges highlighted the need for increased exposure, adequate resources, curriculum alignment, and sufficient instructional time to maximise the benefits of UCTAM for pre-service teachers.

5.3 Conclusions

The study investigated the effects of Unplugged Computational Thinking Activities in Mathematics (UCTAM) on pre-service teachers' (PSTs) computational thinking skills,

their perceptions of UCTAM, and the challenges they encountered during its implementation. The following conclusions were drawn:

1. Pre-service teachers generally had low computational thinking skills at baseline. Most demonstrated emerging or developing proficiency levels, with pattern recognition emerging as the strongest CT component and decomposition as the weakest, indicating gaps in their foundational computational thinking competencies before the intervention.
2. The computational thinking skills of pre-service teachers showed substantial improvement. The improvement was evident across all CT components, with pattern recognition showing the highest gains, followed by abstraction, decomposition, and algorithmic thinking, demonstrating that UCTAM was effective in enhancing PSTs' CT skills.
3. The study showed that UCTAM had a strong positive effect on pre-service teachers' computational thinking skills compared to traditional teaching methods. The experimental group significantly outperformed the control group in overall CT skills and across specific CT components, and there were notable improvements in systematic problem-solving, confidence, and collaborative learning behaviours among PSTs who engaged in UCTAM.
4. Pre-service teachers perceived UCTAM as highly effective for learning mathematics. They believed it enhanced their problem-solving abilities, conceptual understanding, motivation, confidence, creativity, and collaborative learning experiences. However, despite these positive perceptions, many PSTs lacked confidence in implementing UCTAM independently in their future teaching.
5. The study revealed that pre-service teachers faced challenges in learning

mathematics through UCTAM. These included a lack of familiarity with the approach, insufficient resources, alignment with the existing mathematics curriculum, and time constraints during lessons, highlighting the need for increased exposure, adequate resources, curriculum integration, and sufficient instructional time to maximise the benefits of UCTAM for pre-service teachers.

5.4 Recommendations

Based on the findings and conclusions of the study, the following recommendations are proposed for mathematics teachers in the two colleges under study to enhance pre-service teachers' computational thinking skills through Unplugged Computational Thinking Activities in Mathematics (UCTAM):

1. Colleges of Education involved in the study, organised professional development programmes to build mathematics teachers' knowledge and skills in computational thinking concepts and UCTAM activities.
2. Mathematics departments are encouraged to adopt and refine the researcher's UCTAM modules to produce practical teaching guides with illustrative examples and step-by-step instructions for classroom application.
3. Microteaching sessions and practicum experiences should be structured to provide pre-service teachers with opportunities to plan and teach mathematics lessons using UCTAM, thereby building their confidence in applying the approach.
4. College administrators provide adequate UCTAM teaching materials and adjust lesson timetables to allocate sufficient time for UCTAM activities.
5. Future researchers conduct longitudinal studies in similar Colleges of Education to examine the long-term effects of UCTAM on pre-service teachers' computational thinking skills and instructional practices.

5.5 Contributions to Knowledge

The study makes the following contributions to knowledge:

1. The study provides the documented empirical assessment of the baseline computational thinking (CT) skill levels of pre-service teachers in Colleges of Education in Ghana. It reveals generally low proficiency, particularly in decomposition and abstraction, thereby filling a critical knowledge gap in computational thinking education research within the Ghanaian context.
2. The study provides empirical evidence demonstrating that Unplugged Computational Thinking Activities in Mathematics (UCTAM) significantly enhance pre-service teachers' CT skills across decomposition, pattern recognition, abstraction, and algorithmic thinking. This validates UCTAM as an effective pedagogical strategy within teacher education programmes.
3. Structured instructional modules were developed to integrate UCTAM into mathematics instruction for pre-service teachers. These modules include practical lesson plans and activity sequences for systematically teaching each CT component, thereby offering mathematics teacher educators ready-to-use resources to embed computational thinking effectively within their curricula.
4. A practical assessment framework was developed to categorise CT skills into emerging, developing, and proficient levels for each computational thinking component. The framework serves as a valuable tool for guiding future computational thinking evaluations, curriculum designs, and targeted interventions in teacher education programmes.
5. The study identifies specific challenges to integrating UCTAM, including pre-service teachers' lack of familiarity with UCTAM, limited resources, curriculum misalignment, and time constraints. These findings contribute to

knowledge by highlighting the barriers that must be addressed to facilitate the effective adoption of UCTAM in Ghanaian Colleges of Education.



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APPENDICES

Appendix A

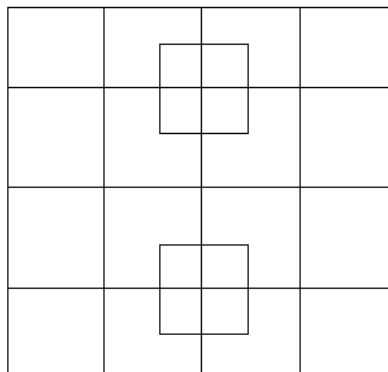
Pre-Test for Pre-Service Teachers

The pre-test is designed to assess your computational thinking skills across four key components: decomposition, pattern recognition, abstraction, and algorithmic thinking. There are a total of eight questions, with two questions under each skill area. Please read each question carefully and answer to the best of your ability.

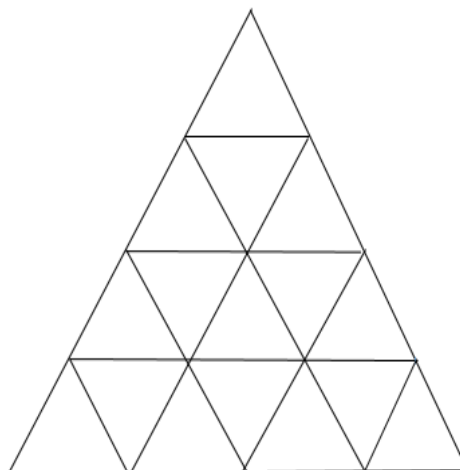
Student ID

A. DECOMPOSITION TASKS

Q1. Study the shape below and determine the total number of squares you can see in the entire shape.

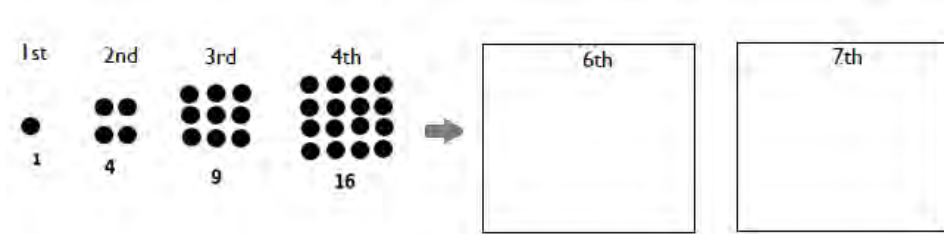


Q2 Study the shape below and determine the total number of triangles you can see in the entire shape.



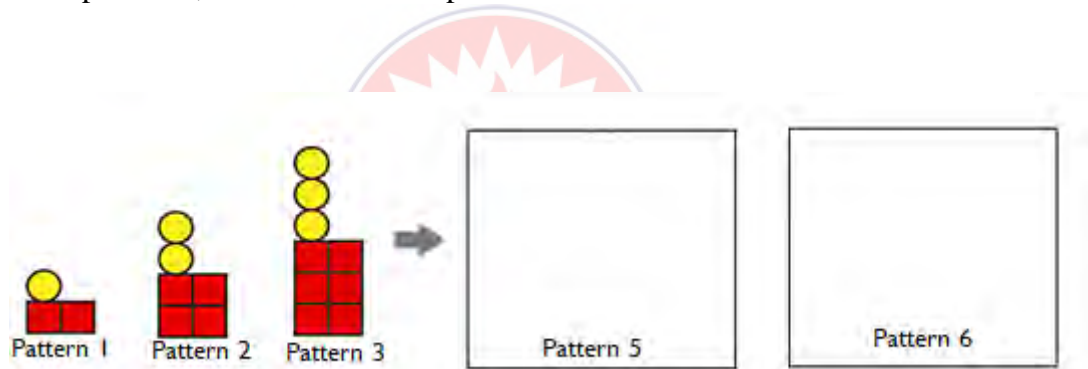
B. PATTERN RECOGNITION TASKS

Q3a Study the pattern of dots in the diagram, and draw in the boxes provided, the sixth and seventh patterns and state the number of dots beneath each.



Q3b How many dots will be in the will be in the 10th pattern if the pattern is extended?

Q4a Study the pattern of squares and circles in the diagram, and draw in the boxes provided, the fifth and sixth patterns.



Q4b What will be the total number of circles and squares in the 10th pattern if the pattern is extended?

C. ABSTRACTION TASKS

Q5a The diagram below shows patterns made with match sticks. Study the pattern of sticks and determine the number of sticks that will be needed to make the tenth pattern.



Q5b What is the rule for the n^{th} pattern?

Q6a. The diagram below shows patterns made with match sticks. Study the number of match sticks in each pattern and complete the table beneath it.



1.

Pattern Number (n)	1	2	3	4	5	6	7	8	...	50
Number of match sticks	5	8	11							

Q6b What is the rule for the n^{th} pattern?

D. ALGORITHMIC THINKING TASKS

Q7. Study the equations and determine the value of each shape

$$\begin{array}{ccccccc}
 \text{Red Trapezoid} & + & \text{Yellow Trapezoid} & + & \text{Blue Trapezoid} & + & \text{Red Trapezoid} & = & 85 \\
 + & & + & & + & & + & & \\
 \text{Red Trapezoid} & + & \text{Green Trapezoid} & + & \text{Red Trapezoid} & + & \text{Yellow Trapezoid} & = & 82 \\
 + & & + & & + & & + & & \\
 \text{Red Trapezoid} & + & \text{Green Trapezoid} & + & \text{Blue Trapezoid} & + & \text{Green Trapezoid} & = & \underline{72} \\
 + & & + & & + & & + & & \\
 \text{Red Trapezoid} & + & \text{Blue Trapezoid} & + & \text{Blue Trapezoid} & + & \text{Blue Trapezoid} & = & 78 \\
 =84 & & =75 & & =78 & & =80 & & \\
 \text{Yellow Trapezoid} & \underline{\hspace{2cm}} & & & \text{Red Trapezoid} & \underline{\hspace{2cm}} & & & \\
 \text{Green Trapezoid} & \underline{\hspace{2cm}} & & & \text{Blue Trapezoid} & \underline{\hspace{2cm}} & & &
 \end{array}$$

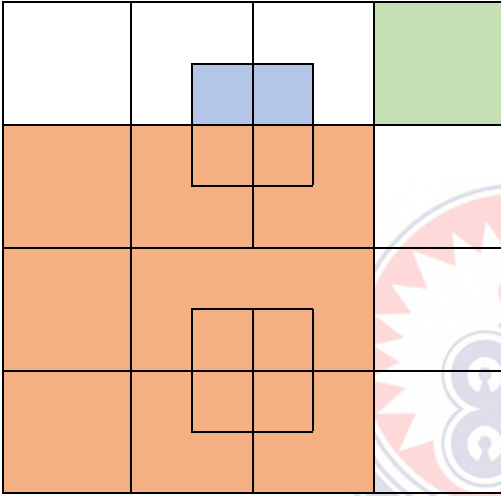
Q8. Study the equations and determine the value of each shape.

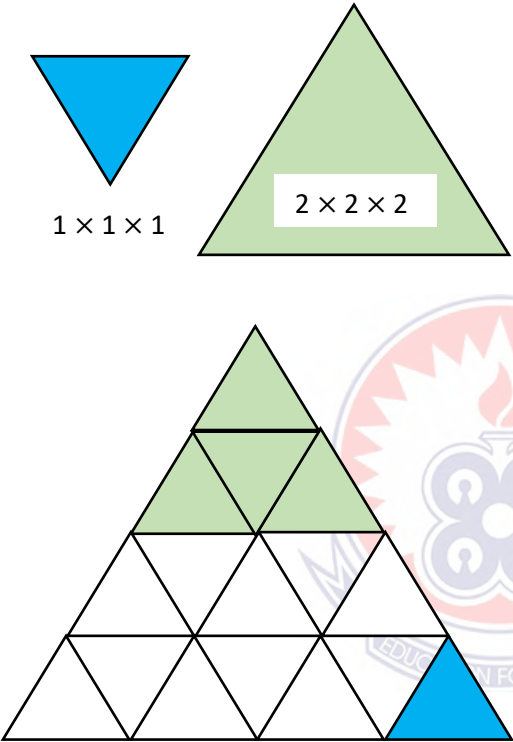
$$\begin{array}{ccccccc}
 \text{Red Diamond} & + & \text{Green Diamond} & + & \text{Blue Diamond} & + & \text{Green Diamond} & = & 74 \\
 + & & + & & + & & + & & \\
 \text{Yellow Diamond} & + & \text{Green Diamond} & + & \text{Yellow Diamond} & + & \text{Yellow Diamond} & = & 79 \\
 + & & + & & + & & + & & \\
 \text{Yellow Diamond} & + & \text{Green Diamond} & + & \text{Red Diamond} & + & \text{Yellow Diamond} & = & 72 \\
 + & & + & & + & & + & & \\
 \text{Blue Diamond} & + & \text{Green Diamond} & + & \text{Red Diamond} & + & \text{Blue Diamond} & = & \underline{62} \\
 =60 & & =100 & & =53 & & =47 & & \\
 \text{Green Diamond} & \underline{\hspace{2cm}} & & & \text{Blue Diamond} & \underline{\hspace{2cm}} & & & \\
 \text{Red Diamond} & \underline{\hspace{2cm}} & & & \text{Yellow Diamond} & \underline{\hspace{2cm}} & & &
 \end{array}$$

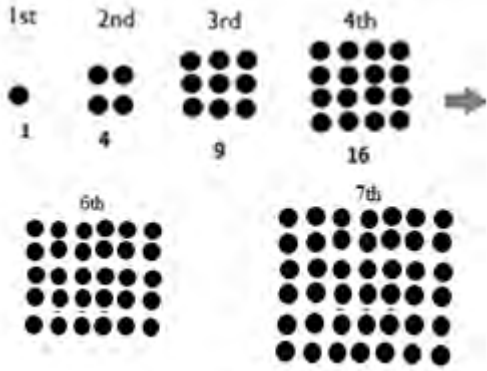
Appendix B

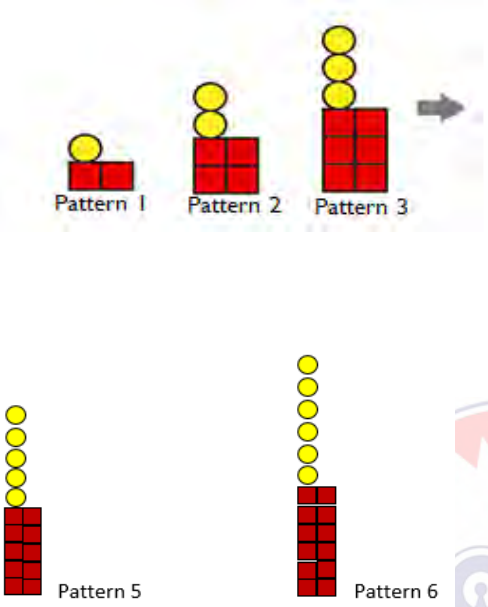
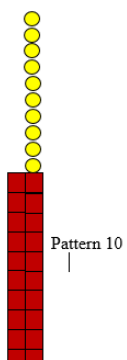
Pre-Test Marking Scheme

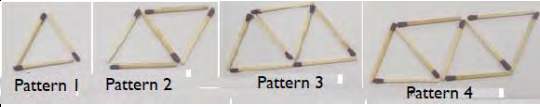
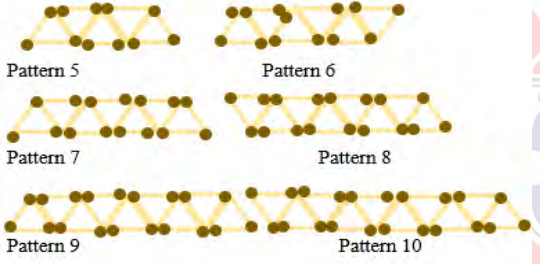

PRE-TEST MARKING SCHEME

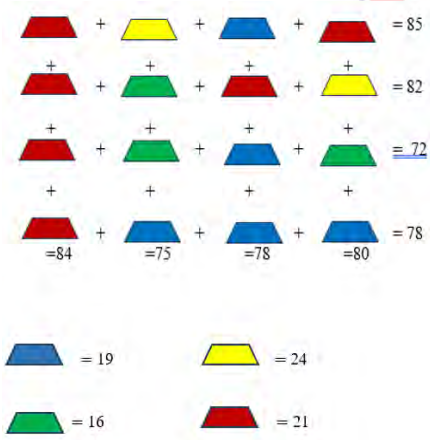
S/N	TEST ITEM/QUESTION	SOLUTION & MARKS	Item Code
DECOMPOSITION TASKS			
Q1	Break down this shape into smaller parts and count how many squares you can see. 	Seeing: a) 1-unit by 1-unit squares (blue squares) b) Number of 1-unit by 1-unit squares = 8 c) 2-units by 2-unit squares (green squares) d) Number of 2-units by 2-unit squares = 18 e) 4-unit by 4-unit squares (green squares) f) Number of 4-units by 4-unit squares = 9 g) 6-unit by 6-unit squares (green squares) h) Number of 6-units by 6-unit squares = 4 i) 8-unit by 8-unit squares (green squares) j) Number of 8-units by 8-unit squares (outer square) = 1 k) Attempting to add a number of each size = $8+18+9+4+1$ l) Obtaining the correct number of possible squares = 40	Q1B1 Q1A1 Q1B2 Q1A2 Q1B3 Q1A3 Q1B4 Q1A4 Q1B5 Q1A5 Q1M1 Q1A6

S/N	TEST ITEM/QUESTION	SOLUTION & MARKS	Item Code
Q2	<p>Study the shape below and determine the total number of triangles you can see in the entire shape.</p> 	<p>Seeing:</p> <p>a) 1-unit by 1-unit by 1-unit triangle (blue triangles) Q2B1</p> <p>b) Number of $1 \times 1 \times 1$ triangles = 16 Q2A1</p> <p>c) $2 \times 2 \times 2$ triangles (green triangles) Q2B2</p> <p>d) Number of $2 \times 2 \times 2$ triangles = 5 Q2A2</p> <p>e) $3 \times 3 \times 3$ triangles (green triangles) Q2B3</p> <p>f) Number of $3 \times 3 \times 3$ triangles = 3 Q2A3</p> <p>g) $4 \times 4 \times 4$ triangles (green triangles) Q2B4</p> <p>h) Number of $4 \times 4 \times 4$ triangles = 1 Q2A4</p> <p>i) Attempting to add a number of each size = $16+5+3+1$ Q2M1</p> <p>j) Obtaining the correct number of possible squares = 25 Q2A5</p> <p>Total Mark = 10</p>	
Q3a	PATTERN RECOGNITION TASKS	<p>Drawing:</p> <p>a) the 6th pattern of dots correctly Q3aB1</p> <p>b) the 7th pattern of dots correctly Q3aB2</p>	

S/N	TEST ITEM/QUESTION	SOLUTION & MARKS	Item Code
	<p>Study the pattern of dots in the diagram, and draw in the boxes provided, the sixth and seventh patterns and state the number of dots beneath each.</p> 		
Q3 b	<p>How many dots will be in the 10th pattern if the pattern is extended?</p>	<p>c) continue drawing to the 10th pattern of dots</p> <p>d) not continuing the drawing to the 10th pattern</p> <p>e) Obtaining the correct number in the 10th pattern = 100</p> <p>Total Mark = 5</p>	Q3aM1 Q3aM2 Q3aA1

S/N	TEST ITEM/QUESTION	SOLUTION & MARKS	Item Code
Q4a	<p>Study the pattern of squares and circles in the diagram, and draw in the boxes provided, the fifth and sixth patterns</p> 	<p>Drawing:</p> <p>a) the 6th pattern correctly</p> <p>b) the 7th pattern correctly</p> <p>Total Mark = 2</p>	<p>Q4aB1</p> <p>Q4aB2</p>
Q4 b	<p>What will be the total number of circles and squares in the 10th pattern if the pattern is extended?</p> 	<p>Total Mark = 3</p>	<p>Q4bM1</p> <p>Q4bM2</p> <p>Q4bA1</p>

S/N	TEST ITEM/QUESTION	SOLUTION & MARKS	Item Code																		
Q5	<p style="text-align: center;">ABSTRACTION TASKS</p> <p>The diagram below shows patterns made with match sticks. Study the pattern of sticks and determine the number of sticks that will be needed to make the tenth pattern.</p>  <p>What is the rule for the n^{th} pattern?</p>  $3 + 2(n-1) = 3 - 2 + 2n$ $= 2n + 1$	<p>a) continue drawing to the 10th pattern</p> <p>b) not continuing to draw but writing the sequence to the 10th pattern, i.e., 21</p> <p>c) obtaining the correct number in the 10th pattern = 21</p> <p>Total Mark = 3</p> <p>d) showing how to obtain the rule for the n^{th} pattern as two times the pattern number plus 1. Obtaining the correct rule for the n^{th} pattern as $n \times 2 + 1$</p> <p>TOTAL MARKS =2</p>	<p>Q5aM1</p> <p>Q5aM2</p> <p>Q5aA1</p> <p>Q5bM3</p> <p>Q5bA2</p>																		
Q6	<p>The diagram below shows patterns made with match sticks. Study the number of match sticks in each pattern and complete the table beneath it.</p>  <table border="1" data-bbox="279 1892 790 2004"> <tbody> <tr> <td>Pattern Number (n)</td> <td>1</td> <td>2</td> <td>3</td> <td>4</td> <td>5</td> <td></td> <td></td> <td>50</td> </tr> <tr> <td>Number of match sticks</td> <td>5</td> <td>8</td> <td>11</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>	Pattern Number (n)	1	2	3	4	5			50	Number of match sticks	5	8	11						<p>a) continue drawing the table to the 50th pattern</p> <p>b) not continuing to draw the table but writing the sequence to the 50th pattern</p> <p>c) Obtaining the correct numbers for the 50th pattern</p>	<p>Q6aM1</p> <p>Q6aM2</p> <p>Q6aA1</p>
Pattern Number (n)	1	2	3	4	5			50													
Number of match sticks	5	8	11																		

S/N	TEST ITEM/QUESTION	SOLUTION & MARKS	Item Code
	What is the rule for the n^{th} pattern?	TOTAL MARKS=3 d) showing how to obtain the rule for the n^{th} pattern as three times the pattern number plus 2. e) obtaining the correct rule for the n^{th} pattern as $n \times 3 + 2$ TOTAL MARKS=2	Q6bM3 Q6bA2
Q7	<p>ALGORITHMIC THINKING TASKS</p> <p>Study the equations and determine the value of each shape</p>  <p> $\text{Red trapezoid} + \text{Yellow trapezoid} + \text{Blue trapezoid} + \text{Red trapezoid} = 85$ $\text{Red trapezoid} + \text{Green trapezoid} + \text{Red trapezoid} + \text{Yellow trapezoid} = 82$ $\text{Red trapezoid} + \text{Green trapezoid} + \text{Blue trapezoid} + \text{Green trapezoid} = 72$ $\text{Red trapezoid} + \text{Blue trapezoid} + \text{Blue trapezoid} + \text{Blue trapezoid} = 78$ </p> <p> $\text{Blue trapezoid} = 19$ $\text{Yellow trapezoid} = 24$ $\text{Green trapezoid} = 16$ $\text{Red trapezoid} = 21$ </p>	Generating the correct equation for red Obtaining the value of red Generating the correct equation for green Obtaining the value of green Generating the correct equation for yellow Obtaining the value of yellow Generating the correct equation for blue Obtaining the value of blue TOTAL MARKS= 8	Q7M1 Q7A1 Q7M2 Q7A2 Q7M3 Q7A3 Q7M4 Q7A4

S/N	TEST ITEM/QUESTION	SOLUTION & MARKS	Item Code
Q8	<p>Study the equations and determine the value of each shape.</p> <p> $\text{Red} = 11$ $\text{Yellow} = 18$ $\text{Green} = 25$ $\text{Blue} = 13$ </p>	<p>a) Generating the correct equation for red</p> <p>b) Obtaining the value of red</p> <p>c) Generating the correct equation for green</p> <p>d) Obtaining the value of green</p> <p>e) Generating the correct equation for yellow</p> <p>f) Obtaining the value of yellow</p> <p>g) Generating the correct equation for blue</p> <p>h) Obtaining the value of blue</p> <p>TOTAL MARKS = 8</p>	<p>Q8M1</p> <p>Q8A1</p> <p>Q8M2</p> <p>Q8A2</p> <p>Q8M3</p> <p>Q8A3</p> <p>Q8M4</p> <p>Q8A4</p>

Appendix C

Pre-service teachers' questionnaire

QUESTIONNAIRE

INSTRUCTION: In each case, tick the appropriate option or write your response.

SECTION A YOUR DEMOGRAPHIC INFORMATION

1. Your Age:

2. Your Gender:

Male

Female

Prefer not to say

3. Year of study in the teacher education program:

1st Year

2nd Year

3rd Year

4th Year



4. Specialism :

Primary Education

JHS

Early Childhood

SECTION B Pre-service Perceptions of Unplugged Computational Thinking

Activities in Mathematics (UCTAM)

For each statement about unplugged computational thinking activities in mathematics, please indicate your level of agreement by ticking the appropriate box on the following

scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree.

S/N	Statements about UCTAM	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	UCTAM have deepened my understanding of mathematical concepts.					
2	UCTAM have enhanced my creative and critical thinking skills.					
3	Participating in UCTAM has improved my understanding of key computational thinking skills, such as abstraction and decomposition.					
4	Engaging in UCTAM has improved my problem-solving skills in mathematics.					
5	UCTAM make learning mathematics more engaging for me.					
6	My motivation to learn mathematics has increased after participating in UCTAM.					
7	UCTAM are easy to design and implement in the classroom.					
8	UCTAM have enriched my learning experience through collaborative activities with my peers.					

9	I feel confident integrating UCTAM into my future mathematics lessons.					
10	I clearly understand how to apply UCTAM in teaching mathematics.					



Appendix D

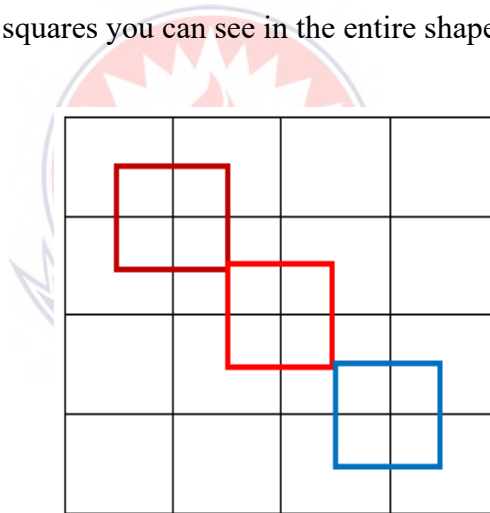
Post Test for Pre-Service Teachers

The post-test is designed to assess your computational thinking skills across four key components: decomposition, pattern recognition, abstraction, and algorithmic thinking. There are a total of eight questions, with two questions under each skill area. Please read each question carefully and answer to the best of your ability.

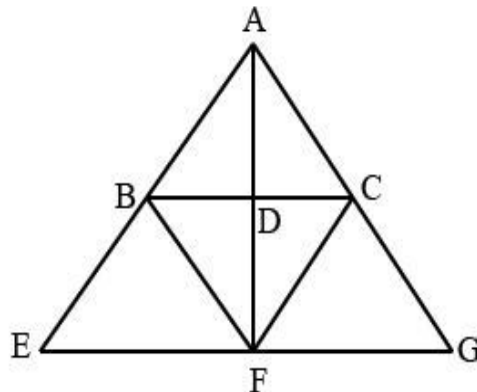
Student ID

A. DECOMPOSITION SKILLS TASKS

- Q1. Examine the shape below, decompose it into smaller sections, and determine the total number of squares you can see in the entire shape.

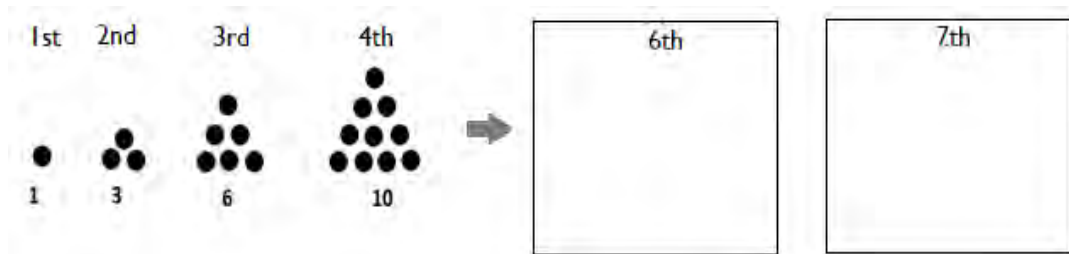


- Q2. Examine the shape below, decompose it into smaller sections, and determine the total number of triangles you can see in the entire shape.



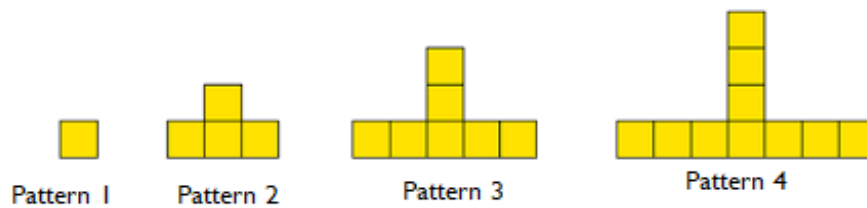
B. PATTERN RECOGNITION TASKS

Q3. Study the pattern of dots in the diagram, and draw in the boxes provided, the sixth and seventh patterns and state the number of dots under each.

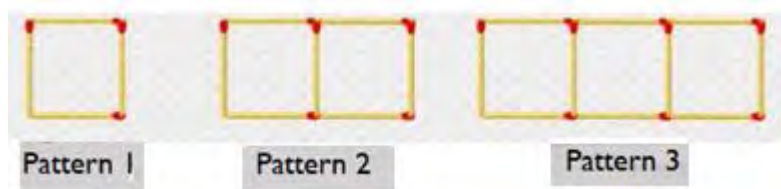


Q4 The diagram below shows patterns made with squares. Study the pattern and determine the number of squares that will be needed to make the tenth pattern.

C. ABSTRACTION TASKS



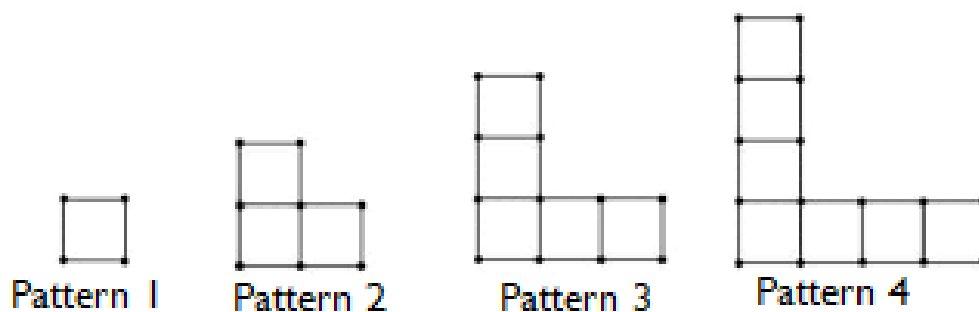
Q5a The diagram below shows patterns made with matchsticks. Study the pattern and determine the number of matchsticks that will be needed to make the tenth



pattern.

Q5b What is the rule for the n^{th} pattern?

Q6a. The diagram below shows patterns made with matchsticks. Study the number of match sticks in each pattern and complete the table beneath it.























Q6b What is the rule for the n^{th} pattern?

D. ALGORITHMIC THINKING TASK

7. Analyze the equations and determine the value of each colour.

$$\begin{array}{ccccccc}
 \text{Blue} & + & \text{Yellow} & + & \text{Yellow} & + & \text{Blue} & = 90 \\
 + & & + & & + & & + & \\
 \text{Green} & + & \text{Green} & + & \text{Yellow} & + & \text{Red} & = 62 \\
 + & & + & & + & & + & \\
 \text{Yellow} & + & \text{Red} & + & \text{Yellow} & + & \text{Red} & = 80 \\
 + & & + & & + & & + & \\
 \text{Red} & + & \text{Red} & + & \text{Yellow} & + & \text{Blue} & = 93 \\
 =80 & & =75 & & =64 & & =106 & \\
 \\
 \text{Green} & \underline{\hspace{2cm}} & & \text{Yellow} & \underline{\hspace{2cm}} & & & \\
 \\
 \text{Blue} & \underline{\hspace{2cm}} & & \text{Red} & \underline{\hspace{2cm}} & & &
 \end{array}$$

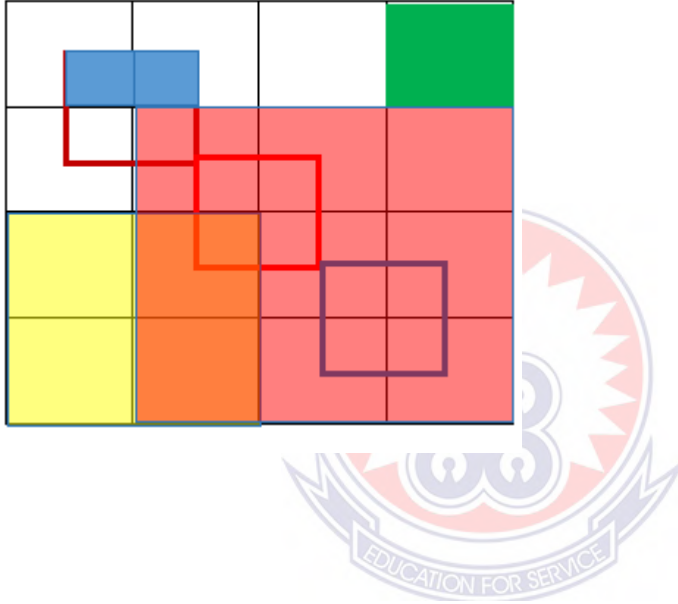
8. Analyze the equations and determine the value of each colour.

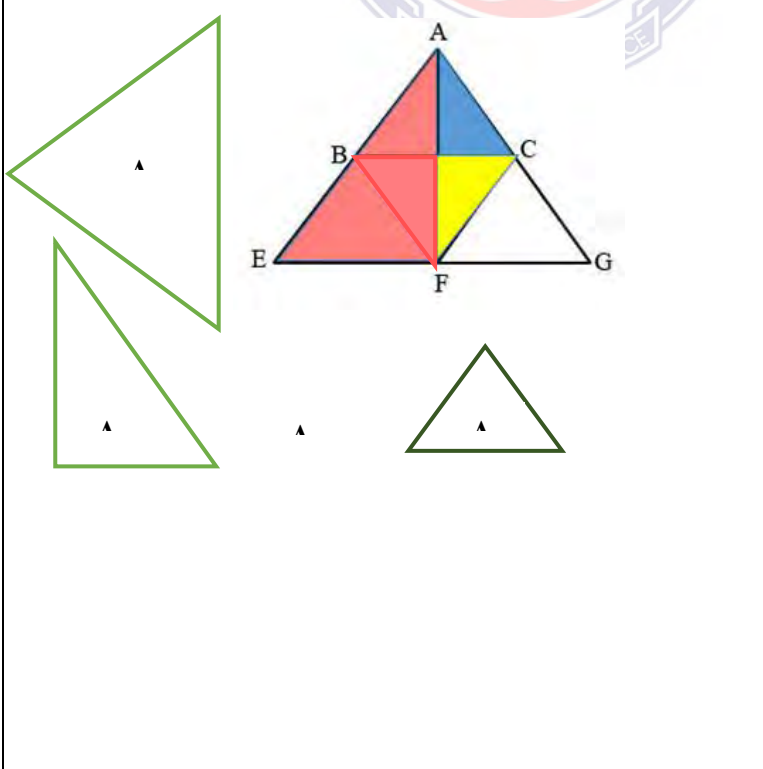
	+		+		+		= 215
+		+		+		+	
	+		+		+		= 217
+		+		+		+	
	+		+		+		= 274
+		+		+		+	
	+		+		+		= 202
<u>= 225</u>		= 198		= 209		= 312	
			_____				_____
			_____				_____

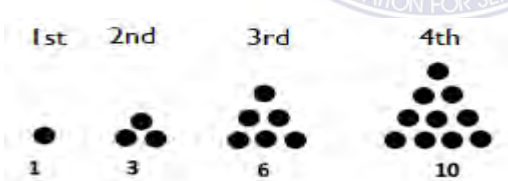
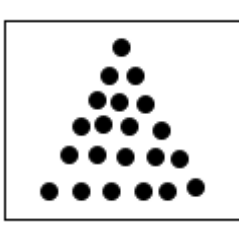
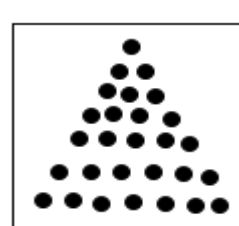


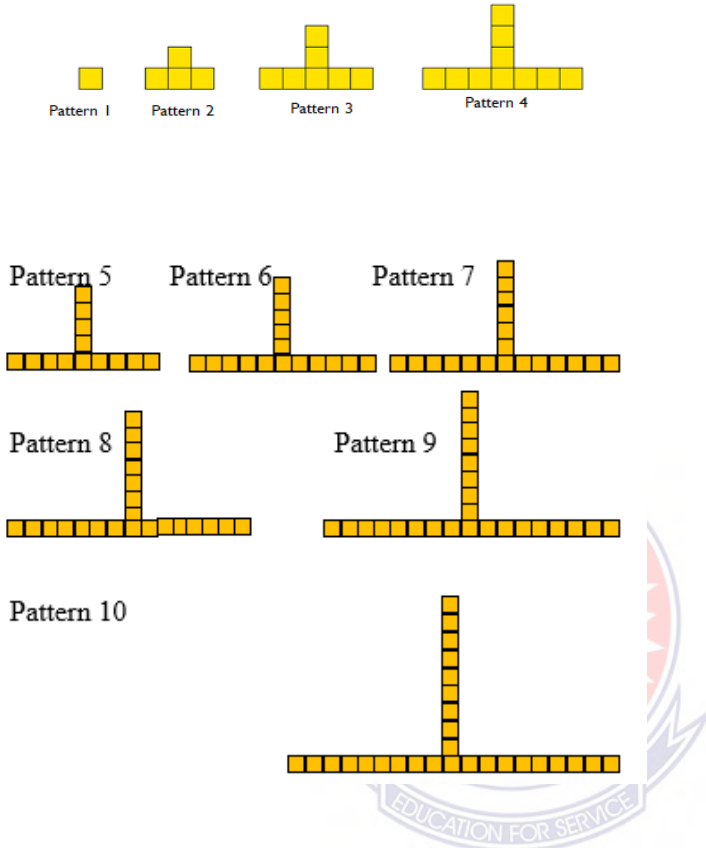
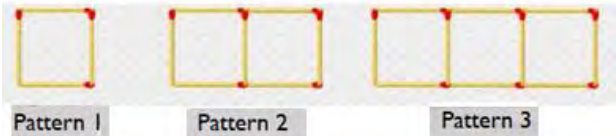
Appendix E

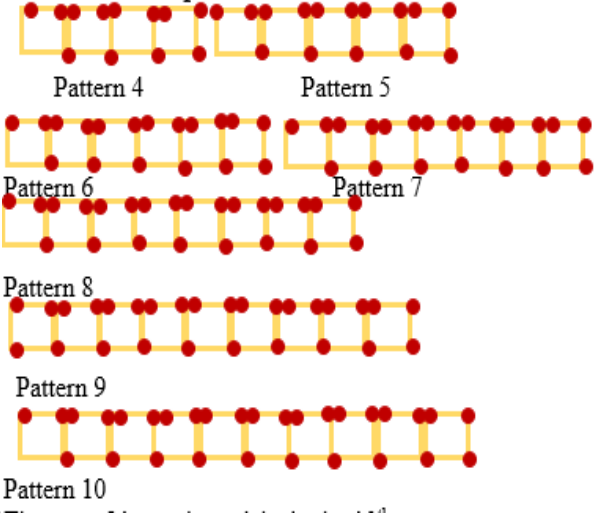
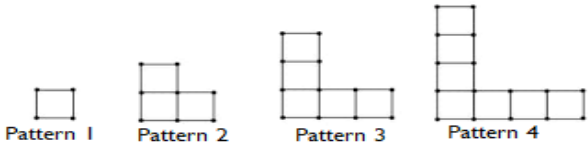
POST-TEST MARKING SCHEME






























































S/N	TEST ITEM/QUESTION,	SOLUTION & MARKS	1 MARK EACH
Decomposition Tasks			
Q1	<p>Examine the shape below, decompose it into smaller sections, and determine the total number of squares you can see in the entire shape.</p> 	<p>Seeing:</p> <p>a) 1-unit by 1-unit squares (blue squares)</p> <p>b) Number of 1-unit by 1-unit squares = 12</p> <p>c) 2-units by 2-unit squares (green squares)</p> <p>d) Number of 2-units by 2-unit squares = 19</p> <p>e) 4-unit by 4-unit squares (yellow squares)</p> <p>f) Number of 4-units by 4-unit squares = 9</p> <p>g) 6-unit by 6-unit squares (red squares)</p> <p>h) Number of 6-units by 6-unit squares = 4</p> <p>i) 8-unit by 8-unit squares (green squares)</p>	<p>Q1B1</p> <p>Q1A1</p> <p>Q1B2</p> <p>Q1A2</p> <p>Q1B3</p> <p>Q1A3</p> <p>Q1B4</p> <p>Q1A4</p> <p>Q1B5</p>

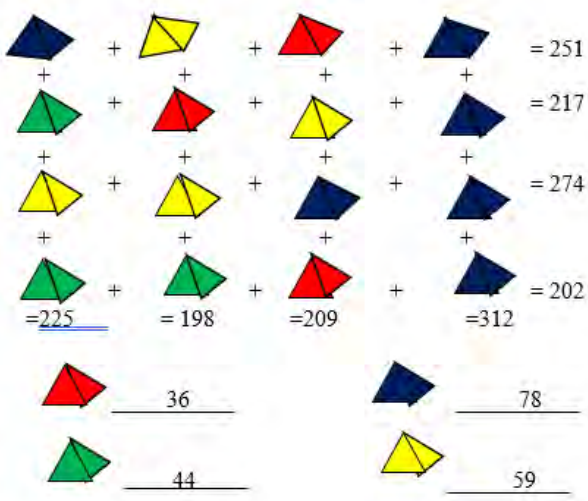
S/N	TEST ITEM/QUESTION,	SOLUTION & MARKS	1 MARK EACH
		j) Number of 8-unit by 8-unit squares (outer square) = 1 k) Attempting to add a number of each size = $12+19+9+4+1$ l) Obtaining the correct number of possible squares = 45 Total Mark = 12	Q1A5 Q1M6 Q1A6
Q2	Examine the shape below, decompose it into smaller sections, and determine the total number of triangles you can see in the entire shape. 	Seeing: Seeing: a) $\Delta 1$ (triangle 1) or (white triangles) b) Number of $\Delta 1 = 4$ c) $\Delta 2$ (triangle 2) or (yellow triangles) d) Number of $\Delta 2 = 4$ e) $\Delta 3$ (triangle 3) (or pink triangles) f) Number of $\Delta 3 = 2$	Q2B1 Q2AI Q2B2 Q2A2 Q2B3 Q2A3

S/N	TEST ITEM/QUESTION,	SOLUTION & MARKS	1 MARK EACH
		<p>g) $\Delta 4$ (triangle 4) or (outer triangle)</p> <p>h) Number of $\Delta 4 = 1$</p> <p>i) Attempting to add a number of each size $=4+4+2+1$</p> <p>j) Obtaining the correct number of possible triangles = 11</p> <p>Total Mark = 10</p>	<p>Q2B4</p> <p>Q2A4</p> <p>Q2M5</p> <p>Q2A5</p>
Q3	<p>PATTERN RECOGNITION TASKS</p> <p>Study the pattern of dots in the diagram, and draw in the boxes provided, the sixth and seventh patterns and state the number of dots under each.</p> <div style="text-align: center;">  <p>1st 2nd 3rd 4th</p> <p>1 3 6 10</p> </div> <div style="display: flex; justify-content: space-around; margin-top: 20px;"> <div style="text-align: center;"> <p>6th pattern</p>  </div> <div style="text-align: center;"> <p>7th pattern</p>  </div> </div>	<p>Drawing:</p> <p>f) the 6th pattern of dots correctly</p> <p>g) the 7th pattern of dots correctly</p> <p>h) Counting the dots correctly</p> <p>The total number of circles in the sixth pattern is 21</p> <p>The total number of circles in the seventh pattern is 28</p> <p>Total Mark = 5</p>	<p>Q3aB1</p> <p>Q3aB2</p> <p>Q3bM1</p> <p>Q3bA1</p> <p>Q3bA2</p>

S/N	TEST ITEM/QUESTION,	SOLUTION & MARKS	1 MARK EACH
Q4	<p>The diagram below shows patterns made with squares. Study the pattern and determine the number of squares that will be needed to make the tenth pattern.</p> 	<p>Drawing:</p> <p>c) the 6th pattern correctly</p> <p>d) the 7th pattern correctly</p> <p>e) Total Mark = 2</p> <p>f) continue drawing to the 10th pattern</p> <p>g) not continuing to draw to the 10th pattern</p> <p>h) Obtaining the correct number in the 10th pattern = 28</p> <p>Total Mark = 3</p>	<p>Q4aB1</p> <p>Q4aB2</p> <p>Q4bM1</p> <p>Q4bM2</p> <p>Q4bA1</p>
Q5	<p>ABSTRACTION TASKS</p> <p>The diagram below shows patterns made with matchsticks. Study the pattern and determine the number of matchsticks that will be needed to make the tenth pattern.</p> 		

S/N	TEST ITEM/QUESTION,	SOLUTION & MARKS	1 MARK EACH																						
	 <table border="1" data-bbox="295 1030 949 1115"> <tr> <td>Pattern Number (n)</td> <td>1</td> <td>2</td> <td>3</td> <td>4</td> <td>5</td> <td>6</td> <td>7</td> <td>8</td> <td>9</td> <td>...</td> </tr> <tr> <td>Number of match sticks</td> <td>4</td> <td>7</td> <td>10</td> <td>13</td> <td>16</td> <td>19</td> <td>22</td> <td>25</td> <td>28</td> <td>...</td> </tr> </table> <p data-bbox="287 1164 742 1209">What is the rule for the n^{th} pattern?</p> $4 + 3(n-1) = 3n + 4 - 3$ $= 3n + 1$	Pattern Number (n)	1	2	3	4	5	6	7	8	9	...	Number of match sticks	4	7	10	13	16	19	22	25	28	...	<p data-bbox="1053 347 1332 448">a) Continue drawing to the 10th pattern</p> <p data-bbox="1053 459 1332 672">b) not continuing to draw but writing the sequence to the 10th pattern</p> <p data-bbox="1053 683 1332 896">c) Obtaining the correct number in the 10th pattern = 31</p> <p data-bbox="1053 907 1252 952">Total Mark = 3</p> <p data-bbox="1053 1008 1332 1332">a) Showing how to obtain the rule for the n^{th} pattern as three times the pattern number plus 1.</p> <p data-bbox="1053 1344 1332 1556">b) obtaining the correct rule for the n^{th} pattern as $n \times 3 + 1$</p> <p data-bbox="1053 1568 1332 1612">TOTAL MARKS =2</p>	<p data-bbox="1364 347 1476 392">Q5aM1</p> <p data-bbox="1364 459 1476 504">Q5aM2</p> <p data-bbox="1364 683 1476 728">Q5aA1</p> <p data-bbox="1364 1008 1476 1052">Q5bM3</p> <p data-bbox="1364 1344 1476 1388">Q5bA2</p>
Pattern Number (n)	1	2	3	4	5	6	7	8	9	...															
Number of match sticks	4	7	10	13	16	19	22	25	28	...															
Q6	<p data-bbox="287 1624 1029 1769">The diagram below shows patterns made with matchsticks. Study the number of matchsticks in each pattern and complete the table beneath it.</p> 	<p data-bbox="1053 1624 1332 1769">a) continue drawing the table to the 50th pattern</p> <p data-bbox="1053 1780 1332 1937">b) not continuing to draw the table but writing the</p>	<p data-bbox="1364 1624 1476 1668">Q6aM1</p> <p data-bbox="1364 1780 1476 1825">Q6aM2</p>																						

S/N	TEST ITEM/QUESTION,	SOLUTION & MARKS	1 MARK EACH																																																																																
	<table border="1" data-bbox="288 349 1023 573"> <tr> <td>Pattern Number (n)</td> <td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>...</td><td>50</td> </tr> <tr> <td>Number of matchsticks</td> <td>1</td><td>3</td><td>5</td><td>7</td><td>9</td><td>11</td><td>13</td><td>15</td><td>...</td><td>99</td> </tr> </table> <p data-bbox="288 629 740 667">What is the rule for the nth pattern?</p> <p data-bbox="288 685 564 723">$1 + 2(n-1) = 2n + 1 - 2$</p> <p data-bbox="288 741 395 779">$= 2n - 1$</p> 	Pattern Number (n)	1	2	3	4	5	6	7	8	...	50	Number of matchsticks	1	3	5	7	9	11	13	15	...	99	<p data-bbox="1098 304 1305 387">sequence to the 50th pattern</p> <p data-bbox="1050 405 1315 607">c) Obtaining the correct numbers for the 50th pattern</p> <p data-bbox="1050 624 1305 663">TOTAL 3 MARKS</p> <p data-bbox="1050 734 1331 1048">d) showing how to obtain the rule for the nth pattern as two times the pattern number minus 1.</p> <p data-bbox="1050 1066 1321 1267">e) obtaining the correct rule for the nth pattern as $n \times 2 - 1$</p> <p data-bbox="1050 1285 1315 1323">TOTAL MARKS=2</p>	<p data-bbox="1362 405 1458 443">Q6aA1</p> <p data-bbox="1362 734 1458 772">Q6bM3</p> <p data-bbox="1362 1066 1458 1104">Q6bA2</p>																																																										
Pattern Number (n)	1	2	3	4	5	6	7	8	...	50																																																																									
Number of matchsticks	1	3	5	7	9	11	13	15	...	99																																																																									
Q7	<p data-bbox="288 1346 804 1384">ALGORITHMIC THINKING TASK</p> <p data-bbox="288 1402 1027 1485">Analyse the equations and determine the value of each colour.</p> <table data-bbox="312 1525 815 1955"> <tr> <td></td> <td>+</td> <td></td> <td>+</td> <td></td> <td>+</td> <td></td> <td>= 90</td> </tr> <tr> <td>+</td><td></td><td>+</td><td></td><td>+</td><td></td><td>+</td><td></td> </tr> <tr> <td></td> <td>+</td> <td></td> <td>+</td> <td></td> <td>+</td> <td></td> <td>= 62</td> </tr> <tr> <td>+</td><td></td><td>+</td><td></td><td>+</td><td></td><td>+</td><td></td> </tr> <tr> <td></td> <td>+</td> <td></td> <td>+</td> <td></td> <td>+</td> <td></td> <td>= 80</td> </tr> <tr> <td>+</td><td></td><td>+</td><td></td><td>+</td><td></td><td>+</td><td></td> </tr> <tr> <td></td> <td>+</td> <td></td> <td>+</td> <td></td> <td>+</td> <td></td> <td>= 93</td> </tr> <tr> <td>=80</td><td></td><td>=75</td><td></td><td>=64</td><td></td><td>=106</td><td></td> </tr> <tr> <td></td> <td colspan="2">_____ 14</td> <td></td> <td></td> <td colspan="2">_____ 16</td> <td></td> </tr> <tr> <td></td> <td colspan="2">_____ 29</td> <td></td> <td></td> <td colspan="2">_____ 24</td> <td></td> </tr> </table>		+		+		+		= 90	+		+		+		+			+		+		+		= 62	+		+		+		+			+		+		+		= 80	+		+		+		+			+		+		+		= 93	=80		=75		=64		=106			_____ 14				_____ 16				_____ 29				_____ 24			<p data-bbox="1050 1346 1315 1485">f) Generating the correct equation for red</p> <p data-bbox="1050 1503 1315 1597">g) Obtaining the value of red</p> <p data-bbox="1050 1615 1315 1765">h) Generating the correct equation for green</p> <p data-bbox="1050 1783 1315 1877">i) Obtaining the value of green</p> <p data-bbox="1050 1895 1315 1989">j) Generating the correct equation for</p>	<p data-bbox="1362 1346 1458 1384">Q7M1</p> <p data-bbox="1362 1503 1458 1541">Q7A1</p> <p data-bbox="1362 1615 1458 1653">Q7M2</p> <p data-bbox="1362 1783 1458 1821">Q7A2</p> <p data-bbox="1362 1895 1458 1933">Q7M3</p>
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S/N	TEST ITEM/QUESTION,	SOLUTION & MARKS	1 MARK EACH
		yellow k) Obtaining the value of yellow l) Generating the correct equation for blue m) Obtaining the value of blue TOTAL 8 MARKS	Q7A3 Q7M4 Q7A4
Q8	Analyse the equations and determine the value of each colour. 	n) Generating the correct equation for red o) Obtaining the value of red p) Generating the correct equation for green q) Obtaining the value of green r) Generating the correct equation for yellow s) Obtaining the value of yellow t) Generating the correct equation for blue u) Obtaining the value of blue TOTAL 8 MARKS	Q8M1 Q8A1 Q8M2 Q8A2 Q8M3 Q8A3 Q8M4 Q8A4

Appendix F

Focus Group Discussion Guide

FOCUS GROUP DISCUSSION

Welcome, Good morning/afternoon, everyone. Thank you for taking the time to join today's focus group interview. Your insights as pre-service teachers in Ghana are incredibly valuable, and I truly appreciate your participation.

Introduction: The purpose of this focus group is to explore your perceptions and the challenges you encounter with the Unplugged CT Activities. We aim to understand how these activities impact your computational thinking skills and conceptual understanding of mathematics. Your feedback will help us identify areas for improvement and develop strategies to better support its implementation in educational settings. This session will last up to two hours. With your consent, we will record this discussion for accurate data analysis. Please let me know if you have any questions about the recording process.

Anonymity: To ensure your privacy, this discussion will be recorded only for transcription purposes. The recordings will be securely stored and destroyed after one year. The transcripts will be anonymised, and no personal identifiers will be linked to your comments. Feel free to skip any questions you prefer not to answer.

Ground Rules: To ensure a productive and respectful discussion, please:

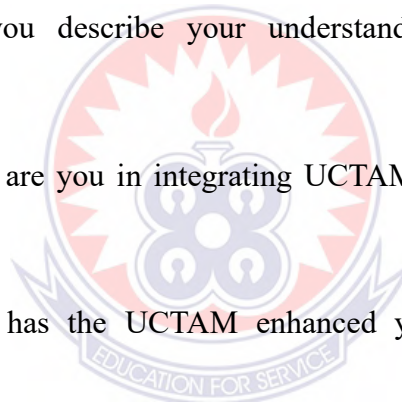
- **Listen Actively:** Respectfully listen to others before sharing your thoughts.
- **Share Diverse Opinions:** This is a safe space for all perspectives; there are no right or wrong answers.
- **Ensure Balanced Participation:** Allow everyone the opportunity to speak.
- **Respect Disagreements:** Engage in constructive and respectful debates.

Do you have any questions about these ground rules? (Address any questions.) Let's begin.

Warm-up: Please introduce yourselves briefly by sharing your name, title, and area of expertise in B.Ed. Education. This will help us understand the diverse perspectives within the group and set the stage for our discussion.

Introductory Question: Before we dive into the discussion, take a moment to reflect on your experiences with the Unplugged CT Activities. Think about specific examples, challenges, and successes you have encountered. This reflection will help focus our conversation on your personal experiences.

- 1: How do you perceive the effectiveness of the UCTAM in Mathematics?
 - a. How would you describe your understanding of UCTAM in learning mathematics?
 - b. How confident are you in integrating UCTAM into your future mathematics lessons?
 - c. In what ways has the UCTAM enhanced your problem-solving skills in mathematics?
 - d. How does UCTAM make learning mathematics more engaging for you?
 - e. How has your motivation to learn mathematics changed after engaging with UCTA?
 - f. How has participating in UCTAM influenced your understanding of key CT skills like abstraction and decomposition?
 - g. How has UCTAM enhanced your learning experience through collaborative activities with peers?



2 What are the main challenges encountered by pre-service teachers in learning mathematics through the Unplugged CT Approach?

- k. How well did your training prepare you to use this UCTAM in your lessons? Can you discuss any gaps you experienced?
- l. How did limited class time affect your ability to implement this approach thoroughly? Can you provide specific examples?
- m. What challenges did you face integrating UCTAM into the existing curriculum?
- n. What difficulties did you encounter in designing effective lessons with UCTAM?
- o. What challenges did you face in adapting your pedagogical methods to UCTAM?
- p. How did your limited knowledge of computational thinking affect your application of UCTAM? Can you provide specific examples?
- q. What challenges did you face regarding access to materials for UCTAM? How did limited access to resources impact your ability to implement UCTAM in your training?

Concluding Question: Is there anything else you would like to share about integrating the Unplugged CT Approach in your classrooms? This could include specific challenges, successes, or additional resources you find helpful.

Conclusion: Thank you for your active participation today. Your insights have been crucial in understanding the integration of the Unplugged CT Approach. If you have further thoughts or questions after this session, please contact me at emmanuelsallah100@gmail.com or 0248056577. All information shared will be kept confidential, with no identifying details linked to any participant responses.

Appendix G

Unplugged Computational Thinking Activities in Mathematics Module (UCTAM)

Week	UCT Focus	CT Learning Goals	Materials	CT Activities	CT Evaluation
1	Decomposition	<ul style="list-style-type: none"> - Analyse and break down geometric shapes into smaller parts. - Classify shapes by size and type. 	Graph paper, rulers, shape cut-outs, measuring tapes	<ul style="list-style-type: none"> - Decompose basic shapes (e.g., squares, rectangles, triangles). - Sketch decomposed parts and classify them using measurements. - Use cut-outs to visualise decomposition. 	<ul style="list-style-type: none"> - Submit a labelled diagram of a decomposed complex shape. - Classify a set of shapes accurately. - Reflect: What helped you decide how to break each shape?
2	Decomposition	<ul style="list-style-type: none"> - Deconstruct multi-step algebraic problems. - Apply algebra tiles to represent and simplify equations. 	Algebra tiles, graph paper, instructional cards	<ul style="list-style-type: none"> - Represent linear equations using algebra tiles. - Break equations into components using the decomposition strategy. - Record and solve using simplified 	<ul style="list-style-type: none"> - Submit solutions to decomposed equations with visual steps. - Include a short explanation of the steps taken. - Reflect: What was challenging about

				steps.	simplifying the equation?
3	Pattern Recognition	<ul style="list-style-type: none"> - Identify, extend, and justify number patterns (triangular, square, pentagonal). - Formulate pattern rules. 	Number charts, pattern blocks, graph paper	<ul style="list-style-type: none"> - Explore and extend number sequences. - Derive rules and use them to predict future terms. 	<ul style="list-style-type: none"> - Create a pattern sequence and extend it correctly. - Submit a written explanation of the rule. - Reflect: How did you verify your pattern rule?
4	Pattern Recognition & Abstraction	<ul style="list-style-type: none"> - Recognize geometric patterns. - Abstract and create new designs by applying transformation rules. 	Shape tiles, graph paper	<ul style="list-style-type: none"> - Explore patterns using tiles. - Design tessellations and pattern strips. - Apply abstraction by extending pattern rules. 	<ul style="list-style-type: none"> - Submit a design with four extended shape sequences. - Describe the transformation or pattern rule used. - Reflect: What made your pattern logical or predictable?
5	Abstraction	<ul style="list-style-type: none"> - Classify numbers using visual techniques. 	Number charts, highlighters, shape cut-	<ul style="list-style-type: none"> - Use number charts to categorise numbers (e.g., 	<ul style="list-style-type: none"> - Submit highlighted number charts.

		- Design composite shapes using basic forms.	outs, graph paper	primes, odds). - Combine simple shapes into new geometric figures.	- Draw and explain a composite figure. - Reflect: How did abstraction help in creating new figures?
6	Abstraction	- Refine number classification using advanced categories. - Create complex abstract figures by combining and modifying shapes.	Number charts, shape tiles, rulers, graph paper	- Classify numbers (e.g., prime, composite, perfect square). - Construct complex geometric shapes through abstraction.	- Complete a number classification challenge. - Submit a sketch of an abstract figure with a construction explanation. - Reflect: What decisions guided your abstract design?
7	Algorithmic Thinking	- Develop and represent step-by-step algorithms to solve systems of equations. - Apply	Flowchart templates, calculators, graph paper, instructional cards	- Create flowcharts for solving systems of equations. - Solve using substitution	- Submit a complete flowchart with all logical steps. - Solve and justify results

		substitution and elimination logically.		and elimination methods.	for a system of equations. - Reflect: Which method was more efficient and why?
8	Algorithmic Thinking	<ul style="list-style-type: none"> - Apply algorithms to graph linear equations and inequalities. - Interpret feasible regions and describe constraints. 	Graph paper, rulers, coloured pencils, plotting guides	<ul style="list-style-type: none"> - Graph linear equations and inequalities on Cartesian planes. - Identify and shade feasible regions. - Write an algorithm for the graphing process. 	<ul style="list-style-type: none"> - Submit a graph showing correct feasible regions. - Submit a written algorithm describing your graphing steps. - Reflect: How did the algorithm help in identifying solutions?

Appendix H

Traditional Instructional Approach Teaching Module

Week	Topic	Objectives	Materials	Instructional Activities	Assessment Tasks
1	Decomposition of Basic Geometric Shapes	<ul style="list-style-type: none"> - Explain the concept of decomposition in geometry - Classify and compare basic shapes by size 	Chalkboard, chalk, rulers, notebooks	<ul style="list-style-type: none"> - Teacher demonstrates how to break down rectangles, squares, and triangles into smaller parts on the board - Students practice measuring and classifying the shapes based on size - Students record observations and classifications 	<ul style="list-style-type: none"> - Solve problems involving the decomposition of basic shapes - Classify shapes by size with accurate measurements - Draw decomposed shapes with correct dimensions
2	Decomposition in Algebra	<ul style="list-style-type: none"> - Use decomposition to simplify and solve linear equations - Apply distributive 	Chalkboard, chalk, notebooks	<ul style="list-style-type: none"> - Teacher models multi-step equation solving using decomposition strategies - Students follow along 	<ul style="list-style-type: none"> - Break down and solve multi-step linear equations - Show all steps, including

		property and combine like terms		and complete guided examples - Class discusses strategies used	distribution and combining like terms - Explain the decomposition process used in solutions
3	Pattern Recognition in Number Sequences	- Identify and describe number patterns (triangular, square, pentagonal) - Generate new terms in each sequence	Chalkboard, chalk, notebooks	- Teacher introduces sequences and explains their structure - Students observe and extend patterns - Students write general rules for each pattern	- Accurately extend number sequences - Derive formulas or rules for sequences - Predict subsequent terms in patterns
4	Pattern Recognition in Geometric Shapes	- Identify recurring patterns in geometric designs - Construct new shapes by continuing observed patterns	Chalkboard, chalk, notebooks	- Teacher presents shape-based patterns on the board - Students copy and expand on patterns - Students create original shapes based	- Reproduce and extend geometric patterns - Generate new shapes by applying identified pattern rules - Justify pattern continuity

				on identified structures	
5	Number Classification and Geometric Abstraction	<ul style="list-style-type: none"> - Classify numbers (prime, odd, composite) using charts - Explore basic geometric abstraction by combining shapes 	Coloured chalk, number charts, notebooks	<ul style="list-style-type: none"> - Teacher demonstrates number classification with colour-coded charts - Students replicate and label categories - Students practice combining shapes to form abstract figures 	<ul style="list-style-type: none"> - Classify numbers accurately into multiple categories - Represent abstract figures by logically combining basic shapes - Label diagrams with appropriate classifications
6	Advanced Classification and Abstraction	<ul style="list-style-type: none"> - Deepen classification skills using overlapping categories - Perform complex geometric abstractions 	Number charts, chalk, notebooks	<ul style="list-style-type: none"> - Teacher introduces refined classifications (e.g., odd primes) - Students classify and label accordingly - Students explore combining multiple shapes to form 	<ul style="list-style-type: none"> - Classify numbers into intersecting sets - Construct and label complex abstract shapes - Explain structure and logic behind each figure

				intricate figures	
7	Algorithmic Thinking: Solving Systems of Equations	- Design step-by-step algorithms to solve systems using substitution and elimination	Chalkboard, chalk, calculators, notebooks	- Teacher presents solving methods as algorithms with flowcharts - Students follow structured steps to solve systems - Students replicate flowcharts and annotate steps	- Create algorithmic flowcharts for solving systems - Accurately solve systems using both methods - Justify each solution with substitution checks
8	Algorithmic Thinking: Graphical Representation of Equations and Inequalities	- Plot linear equations and inequalities - Identify and interpret feasible regions on graphs	Chalkboard, rulers, coloured pencils, notebooks	- Teacher demonstrates graphing on Cartesian plane - Students plot equations and shade regions - Class discusses meaning of constraints and solutions	- Graph linear equations and inequalities precisely - Correctly shade feasible regions - Interpret and explain graphical solutions