# THE SIGNIFICANCE OF INTEGRATING COMPUTATIONAL THINKING EDUCATION INTO MATHEMATICS EDUCATION IN SENIOR PRIMARY SCHOOL

by

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# Statement of Originality

I, LEUNG, Yu Hin certify that this dissertation represents my original work, and that any assistance I received in its preparation is fully acknowledged and disclosed in the text. I have not presented this work, or any part of it, for assessment in any other course or academic program.

To the best of my knowledge and belief, this dissertation contains no material previously published or written by another person, except where due reference is made in the text. Any passages quoted or paraphrased from other sources are clearly indicated, and all sources have been duly acknowledged in the bibliography.

I understand that if it is found that I have breached any of these conditions, appropriate action may be taken by the academic institution, including the possible revocation of my degree.

Herman Yu Hin LEUNG

## Abstract

The Hong Kong Education Bureau's paper titled "Computational Thinking - Coding Education: Supplement to the Primary Curriculum" published in 2020 has been a crucial step towards encouraging CT and coding education in Primary 4 to Primary 6 in Hong Kong. With technology increasingly being utilized in various industries, it has become crucial for students to acquire knowledge and skills necessary to thrive in the digital era. Computational Thinking (CT) has been demonstrated as a method of problem-solving that has helped students become better problem solvers and fostered a deeper understanding of mathematical concepts. Therefore, incorporating CT into Mathematics Education (ME) has become a subject of much research in recent years, especially since systematic reviews have been carried out.

In line with the Hong Kong Education Bureau (EDB)'s proposal, the Hong Kong Curriculum Development Council (CDC) has also emphasized the value of CT and coding instruction in preparing students for the digital era. Thus, the three-year study that has been conducted from January 2021 to May 2023 aims to examine the significance and impact of integrating CT into ME in senior primary education in Hong Kong.

This study has concentrated on Hong Kong senior primary children, particularly those in Primary 6, and has employed a multi-phase approach. Initially, a comprehensive review of the current state of research on CT and ME has been conducted to inform the study design. Subsequently, data has been gathered from students, teachers, and schools using surveys and assessments. Statistical techniques have been applied to evaluate the collected data, focusing on establishing the relationship between CTE and ME, analyzing students' motivation to learn

mathematics through CTE, and identifying the advantages of incorporating CTE into ME, including its impact on students' mathematical performance.

The study uncovered several key findings concerning the integration of CT into ME in senior primary schools. First, incorporating CT can boost students' engagement and motivation in mathematics by making the subject more relevant and captivating. Second, CT can support the development of mathematical thinking and problem-solving skills by offering tools and approaches that encourage critical and creative thinking. Third, CT can foster students' understanding of mathematical concepts and processes by providing visual and interactive representations of these concepts and processes.

Preliminary findings indicate a positive correlation between the integration of CT into mathematics instruction and improved problem-solving skills among students. Additionally, students who have been exposed to CT-based activities have demonstrated increased interest and success in arithmetic. These results are in alignment with prior studies conducted by Kong et al. (2018) and Benton et al. (2018).

The results of this study are expected to provide significant insights into the advantages of incorporating CTE into mathematics instruction, inform the creation of educational policies in Hong Kong and elsewhere, and prepare students adequately for the digital era. The study will also contribute to the expanding body of research on CT and ME and inform future research on the subject.

**Keywords**: Education, Coding, Computational Thinking, Mathematics, STEAM

# Preface

I, Herman Leung, am an accomplished educator with a strong passion for mathematics education. My academic journey has taken me through various stages, including the completion of a Bachelor's degree (Dean’s List) from Deakin University in Australia, a Master of Arts degree in Mathematics and Pedagogy (Dean’s List), and currently, the pursuit of a Doctor of Education in Mathematics Education at The Education University of Hong Kong.

Throughout my career, I have had the opportunity to contribute to the field of education in multiple capacities, which include roles as a lecturer in Hong Kong Baptist University, course developer and Postgraduate Diploma in Education (Primary) tutor in Hong Kong Metropolitan University, head of ICT Education & STEAM Education, head of Teacher Professional Development, head of eLearning and Online Learning in PLK HKTA Yuen Yuen Primary School. I have had the privilege of sharing my insights and experiences as a guest speaker at esteemed institutions such as MIT, HKFEW, GCCCE, HKMEC, EdUHK, HKMU, and USM. My dedication to the field has been recognized through various awards, including The 4th Professor Siu Man Keung Mathematics Teacher Excellence Paper Award by the Hong Kong Association for Mathematics Education in 2023, The Outstanding Teacher Award Winner - School-based Management Section by the Hong Kong Federation of Education Workers - Outstanding Teacher Election in 2022, The President's Awards for Excellence in Inspirational Teaching by Hong Kong Metropolitan University in 2022, The Top 10 STEM Teacher Award by the HKNETEA The Greater Bay Area STEM Excellence Award Scheme in 2022, and The SDL-STEM Innovation School Award and Learning Design Award by the Hong Kong University in 2021, among others.

In my years as an educator, I have been driven by the desire to create a supportive and inclusive learning environment that fosters curiosity and exploration among students. This commitment to empowering learners has led me to pursue research in the area of mathematics education for my Doctor of Education dissertation.

This dissertation is a culmination of my research efforts and a testament to my dedication to advancing mathematics education. It is my hope that the findings and insights presented herein will contribute to the development of effective instructional strategies and enhance the overall learning experience for students across diverse backgrounds and abilities. I am deeply grateful to my supervisors, my colleagues, friends, and family who have supported and encouraged me throughout this journey.

## Acknowledgements

Completing my studies and dissertation over the past four years has been an incredible journey, during which I have experienced significant growth as a researcher and data analyst. I am grateful for the invaluable guidance provided by my wonderful supervisors and the continued support of my beloved family and friends.

I want to start by expressing my gratitude to Dr. POON Kin Keung, my Principal Supervisor, and Dr. CHAN Wing Sum, Associate Supervisor, for their leadership, encouragement, and support throughout the entire process. Their guidance and knowledge were really helpful to me as I shaped the course of my research and realized my ideas.

My dear family, I owe my achievement to your unwavering support. Mom and dad, from the very beginning of my life, you have loved and supported me, instilling in me the values of life, knowledge, and hard work, and encouraging me to pursue my dreams. My wife, your belief in me, encouragement, love, and insightful feedback have been invaluable throughout the process. To my sister, thank you for your loving and supportive phone calls and messages. Having all of my family members with me on this journey fills me with gratitude beyond words.

Lastly, I would like to extend my heartfelt appreciation to all the study participants who generously invested their time, shared their experiences, and offered their insights. Their willingness to partake in my research was instrumental to its success, and I am deeply grateful for their involvement. Ultimately, without the support and participation of numerous individuals, this scholarly endeavor would not have been feasible. I wish to convey my profound gratitude to everyone who contributed to this undertaking and express my hope that the field will benefit from the valuable perspectives we have presented.

# Table of Contents

# List of Abbreviations

| | |
|---|---|
| **CT** | Computational Thinking |
| **CTE** | Computational Thinking Education |
| **ME** | Mathematics Education |
| **STEAM** | Science, Technology, Engineering, Arts and Mathematics |
| **PBL** | Problem-based Learning |
| **DBL** | Design-based Learning |
| **ZPD** | Zone of Proximal Development |
| **TPACK** | Technological, Pedagogical, and Content Knowledge |
| **TK** | Technological Knowledge |
| **PK** | Pedagogical Knowledge |
| **CK** | Content Knowledge |
| **TA** | Teaching Assistant |
| **PRISMA** | Preferred Reporting Items for Systematic Reviews and Meta-Analyses |
| **EdUHK** | The Education University of Hong Kong |
| **EdB** | Education Bureau |
| **EMI** | English Medium Instruction |
| **DSS** | Direct Subsidy Scheme |
| **NET** | Native-speaking English Teacher |
| **SLR** | Systematic Literature Review |

## List of Figures

**List of Tables**

# 1. INTRODUCTION

## 1.1 Background of the Study

CT has received a lot of attention recently in a number of policy efforts (Bocconi et al., 2022; Hsu et al., 2018). Even though it has been acknowledged as a crucial 21st-century skill for fostering children's critical thinking, analytical skills, creativity, and problem-solving abilities (Kassa & Mekonnen, 2022; Voogt et al., 2015), there is still disagreement over the precise definition and scope of CT (Caeli & Bundsgaard, 2020; Lyon & Magana, 2020; Rich et al., 2021; Sands et al., 2018;). Even if there is no consensus, it's interesting to note that a number of nations have already implemented CT into their educational curriculum, often choosing science and mathematics as the logical topics for its integration (Weintrop et al., 2016). Papert (1980) suggested that learning to program computers changes the learning process itself, making it more active, personal, and self-directed, where the argument is based on Piaget's views on cognitive development. According to Papert's constructionism theory (Ackermann, 2001; Papert, 1980; Leron & Hazzan, 1998), learning results from the active construction and transformation of ideas communicated via different media, within particular settings, produced through interactions, and modified by individual minds. Initially relating mathematics and programming, Papert eventually broadened the idea to include thinking and learning in a variety of subject areas, such as science and literature (Papert, 1980). However, due to the difficulties in learning coding languages and the implementation of activities that did not resonate with children's interests, Papert's concept of "CT for all" encountered obstacles (Resnick et al., 2009). Studies on Logo programming showed that teachers offered more support than direct instruction, and only a small number of students saw improvements in their thinking skills (Kurland et al., 1986; Pea & Kurland, 1983). As a result, the use of Logo programming in educational settings declined within a decade, mainly due to inadequate integration with academic subjects and a shortage of trained educators (Noss and

Hoyles, 1996). The importance of CT in education was revitalized by Wing's (2006) description of it as the ability to solve problems, design systems, and understand human behavior. Following Wing's call for CT to become a universally available skill for children and the ensuing discussions about its definition, many researchers have attempted to clarify the confusion surrounding the discourse on CT in education (Grover & Pea, 2013; Israel et al., 2015; Roussou & Rangoussi, 2020; Zhan et al., 2022). According to Grover and Pea (2013), CT is a crucial tool for supporting cognitive tasks and is a fundamental ability needed for successful and efficient problem-solving (Shute et al., 2017). Particularly when CT incorporates non-computer-based problem-solving activities, sometimes known as "unplugged" activities, the line between programming and CT is still unclear. Grover and Pea (2013) have criticized unplugged activities, claiming that they deprive students of essential computing experiences. This study presents an overview of the CT-related activities that have been investigated in primary ME research as well as the integration of CT into ME, as studied in different studies, rather than trying to establish a clear definition of CT. Due to the ambiguity of the word "CT," many classification schemes have been used to describe its activities. For instance, whereas CT activities is concentrated including data analysis, modeling and simulation, computational problem-solving, and systems thinking (Weintrop et al., 2014; Weintrop et al., 2016). Brennan and Resnick (2012) utilized CT principles, methods, and viewpoints. Shute et al. (2017), on the other hand, used CT features such decomposition, abstraction, algorithms, debugging, iteration, and generalization. The tasks, procedures, and viewpoints used in basic mathematics classes are referred to as "CT activities" in this study.

There is agreement on the potential advantages of using CT in ME. Researchers have investigated CT as a problem-solving approach that makes use of computational methods to assess and solve complicated issues (Barr & Stephenson, 2011; Voskoglou & Buckley, 2012). CT entails dissecting complex issues into simpler chunks, seeing patterns and linkages, and coming up with methodical solutions. Students' problem-solving, critical thinking, and creative talents have improved as a result of the CT's inclusion in mathematics teaching. For instance, Voogt et al. (2018) performed research comparing pupils who received standard ME with those who received training based on the CT. The findings showed that students who received education based on CT had improved problem-solving and critical thinking capabilities. These pupils also showed more involvement and drive in their study of mathematics. Students learn the abilities to use technology for problem-solving, data analysis, and creativity by introducing CT into mathematics instruction, therefore preparing them for the needs of the digital age in the 21st century. It is more important than ever for students to acquire the skills necessary to succeed in a world driven by technology as technology continues to transform a variety of disciplines. Students are given the skills to use technology successfully via the incorporation of CT into mathematics teaching, which also improves students' ability to think critically, be creative, and solve problems (Adler et al., 2022; Aizikovitsh-Udi & Cheng, 2015). As additional research is undertaken and the advantages of CT-based ME become more clearly evident, it is anticipated that this trend toward incorporating CT into mathematics teaching will continue to gain steam. As a result, educators are likely to adopt this strategy in their efforts to improve mathematics instruction and provide students the skills they need to succeed in the digital era.

CT is a technique for addressing problems that employs computational techniques for both problem analysis and resolution (Peyret & Taylor, 2012). It requires the use of several different skills, including abstraction, algorithmic reasoning, pattern detection, and decomposition. A lot of nations have official curriculums that incorporate CTE. It's thought to be a skill that will be essential in the twenty-first century. Many nations currently include CTE in their national curricula since it has been determined that CT is a necessary ability for the twenty-first century (Glovers et al., 2013). In addition to helping students, integrating CT into math instruction might help teachers run interesting and productive lessons (Lee et al., 2020). CT offers teachers a framework for planning lessons that foster student participation and group problem-solving while promoting learning. Students may gain from the usage of CT in math classrooms in a variety of ways. CT may assist students in breaking down difficult issues into smaller, more manageable chunks, for instance, to help them recognize patterns and links that may lead their approach to problem-solving. CT may also foster innovation and creativity by encouraging students to experiment with new ideas and consider other approaches to solve problems (Israel-Fishelson & Hershkovitz, 2022). Integrating CT might be a useful tool to enhance students' problem-solving abilities, encourage innovation and creativity, and support effective teaching methods. As a result, it is crucial that decision-makers and experts in the area of education pay close attention to it.

In Hong Kong, senior primary school students generally vary in age from 9 to 11 years old. At this age, students are gaining problem-solving skills and starting to be able to understand abstract concepts according to Piaget’s Cognitive Development Theory (Thomas, 1985). So now is the ideal moment to introduce CTE and integrate it into the teaching of mathematics. Examining the benefits of using CTE in senior primary school mathematics instruction is the goal of this research. It will focus on how effectively CT integration in ME lessons enhances students' mathematical performance and learning interest in particular. With good cause, there has been an increase in interest recently in the integration of CT into the teaching of mathematics in elementary schools. In the twenty-first century, CT— the act of breaking issues down into smaller, more manageable bits and creating algorithms to solve them—is a crucial ability (Rich et al., 2019). The goal of CTE is to help students improve their problem-solving, pattern-spotting, abstraction, algorithmic thinking, and debugging abilities. Students in senior primary school are at a crucial juncture in their cognitive development, moving from concrete to abstract thought. Senior primary students, especially grade 4 and 6 are starting to comprehend intricate ideas and are capable of finding solutions on their own. So, this age is perfect for introducing CTE and incorporating it with math instruction. Students may enhance their arithmetic ability and acquire superior problem-solving abilities by integrating CT teaching into ME. Studies have shown that pupils' mathematics skills may benefit from receiving CT teaching. According to research by Vogt et al. (2015), students who got CT teaching in addition to their usual mathematics training outperformed those who did not get CT instruction on arithmetic examinations. The research also showed that students' ability to break down difficult issues into smaller, more manageable tasks and create algorithms to solve them improved as a result of their exposure to CT training. Additionally, including CT teaching into math instruction may assist students be ready for the demands of the modern workforce (Snalune, 2015). Since many modern occupations entail dealing with data, analyzing information, and creating algorithms to solve issues, it is essential for individuals to be strong in CT abilities (Pedro et al., 2019). Students may acquire these abilities early on and be better equipped for future employment options by introducing CTE at a young age. Students stand to gain significantly from the inclusion of CT teaching in senior primary school mathematics curriculum. It may assist children in improving their mathematical abilities, problem-solving abilities, and readiness for the demands of the workforce in the twenty-first century. Therefore, it is imperative that teachers take CTE into account while developing their mathematical curriculum.

## 1.2 Statement of the Problem

The integration of CTE inside ME has developed into a major research problem for a long length of time in recorded history. Since there is a growing consensus that CT skills are crucial in the modern world, it is imperative to provide students access to these capabilities at an early age. CT is a strategy for solving problems that entails breaking big problems down into smaller, more manageable parts using logic and mathematics. The primary focus of ME is the study of mathematical concepts and methods, such as those found in arithmetic, algebra, geometry, calculus, statistics, and probability. However, both CT and ME attempt to strengthen their students' analytical and problem-solving abilities. CT may be included into ME in order to impart these concepts more deeply and better equip students for future challenges. According to the National Research Council (2011), developing students' CT skills is essential for preparing them for a rapidly changing technological world. These skills could help students improve their ability to communicate clearly, analyze critically, and solve complex problems. The Council emphasized the need of including mathematics instruction into the K–12 curriculum that encourages CT. The research claims that this integration may help students better understand mathematical concepts, develop their ability to apply such concepts in real-world situations, and enhance their learning interest in mathematics.

Additionally, recent research has emphasized the advantages of including CT in ME. According to a research by Barcelos et al. (2018), students who received CTE in addition to regular mathematics teaching significantly improved their problem-solving and CT abilities. According to another research by Mohtadi et al. (2013), including CT into mathematics instruction may improve students' knowledge of mathematical ideas and motivate them to learn more about them. ME that incorporates CT has the ability to close a number of knowledge gaps and provide students the tools they need to use technology effectively and solve challenging challenges. This study seeks to investigate and assess the effects of integrating CTE into ME in senior primary school since the efficiency of this integration is yet unknown (Korkmaz et al., 2017). Because CTE is not incorporated into senior primary school mathematics curricula, it is a serious issue that students are unable to effectively develop the critical problem-solving, logical reasoning, and algorithmic thinking skills necessary for success in a rapidly changing digital environment. By integrating CTE into mathematics teaching, it may be able to narrow this gap and provide students the knowledge and skills they need to become proficient at utilizing technology and solving difficult issues. This research aims to explore and evaluate the impacts of integrating CTE into senior primary school ME teaching since the effectiveness of this integration is still up for debate.

### 1.3 Research Questions

The research problem identified is the significance of integrating CTE into ME in senior primary school. To address this problem, this study aims to answer the following research questions to help achieve the research objectives:

- Research Question 1: [RELATIONSHIP] What is the relationship between CTE and ME? What are the roles of CT Concepts (Coding Skills), CT Practices (Problem-solving Skills) and CT Perspectives (Identity and Motivation) in ME from educators' and students' perspectives?
- Research Question 2: [ACADEMIC PERFORMANCE] How students are benefiting from integrating CTE into ME? What are the effects of the integration implementation to students' performance in mathematics?
- Research Question 3: [LEARNING MOTIVATION] Are students motivated to learn mathematics through coding activities in CTE?

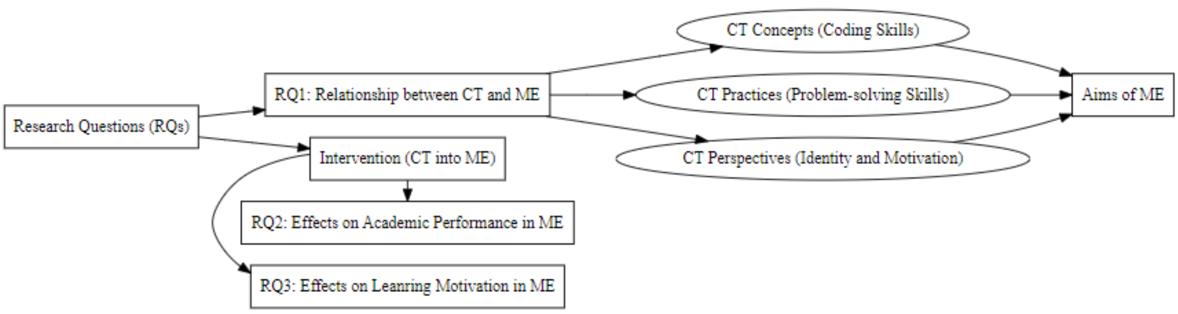



Figure 1. Research Framework

## 1.4 Study Objective

### 1.4.1 General objective

The broad objective of the study is to determine the Significance of Integrating CTE into ME in Senior Primary Schools.

### 1.4.2 Specific objective

- To explore the current status of CTE and ME in senior primary schools.
- To examine the relationship between CT and ME in senior primary schools.
- To investigate the impact of integrating CTE into ME on students' academic performance and students' learning interest in ME in senior primary schools.
- To recommend policy implications for integrating CTE into ME in senior primary schools.

## 1.5 Research Hypothesis

Based on the research questions and the information provided, the hypotheses are:

- There is a significant positive relationship between the integration of CTE and the improvement of students' mathematical performance in senior primary school.

The improvement in students' arithmetic performance in senior primary school is predicted to be positively correlated with the incorporation of CTE, according to this hypothesis. The goal of the research is to find out whether adding CTE to mathematics lessons may significantly increase students' mathematical performance. A beneficial effect on students' mathematical performance is predicted if CTE is included into mathematics instruction, according to the hypothesis.

- The integration of CTE into ME significantly enhances students' problem-solving skills in senior primary school.

According to this hypothesis, pupils' ability to solve problems in senior primary school may be greatly improved by including CTE into mathematics instruction. Students will acquire stronger problem-solving abilities, according to the hypothesis, if CTE is included into mathematics curriculum. The purpose of the research is to find out whether teaching students about CT may significantly improve their problem-solving abilities when it is integrated into mathematics instruction.

- There is a significant positive relationship between the integration of CTE and the motivation of students to learn mathematics in senior primary school.

According to this hypothesis, the desire of pupils to study mathematics in senior primary school is positively correlated with the integration of CTE. The study's goal is to find out whether adding CTE to math lessons may make pupils more motivated to learn the subject. According to the hypothesis, integrating CTE into mathematics instruction will increase students' learning motivation and interest in mathematics.

- What are the existing practices for integrating CT and mathematics in senior primary schools?
- What is the possible research hypothesis for the significance of integrating CTE into ME in senior primary school is:

"Hypothesis: Integrating CTE into ME in senior primary school will lead to improved problem-solving skills, increased learning motivation and academic performance in mathematics, and better preparation for future careers in technology and related fields." This hypothesis proposes that integrating CTE into ME can have several positive outcomes.

The academic performance and attitudes of students who get CT instruction as part of their mathematics curriculum with those who do not might be compared in a study to test this idea. Data on students' aptitude for learning motivation and interest in mathematics might be gathered, and the data could then be analyzed to see if there are any notable differences between the two groups.

If the statistics are consistent with the hypothesis, it might have significant ramifications for educators and policymakers since it would demonstrate the value of incorporating CTE into the teaching of mathematics in senior primary schools. It might also help with the creation of future educational policies and initiatives that attempt to raise student achievement levels and get them ready for professions in technology and related industries.

## 1.6 Potential Benefits of Integrating CT into ME

Students stand to gain a lot from the incorporation of CT into ME. The use of CT concepts and approaches in ME might enhance students' capacity for logical reasoning, problem-solving, and critical thinking. (Barr et al., 2011) claim that computational tools are used in CT to examine and resolve issues. Students may learn to approach issues more methodically and analytically by dividing them into smaller, more manageable components by introducing CT into ME.

Additionally, including CT within ME may aid in preparing students for future occupations that need CT expertise (Leonard et al, 2016). Workers with CT skills are in great demand in the job market right now, especially in professions like STEAM careers (Grover & Pea, 2013). Students may better grasp the real-world uses of CT in various sectors and become more prepared for the workforce by integrating CT into ME.

## 1.7 Scope of the Study

The comprehensive three-year research study is set to be conducted from January 2021 to May 2023. A combination of pre- and post-tests, surveys, interviews, lesson observations, and other data collection methodologies will be employed in the project to amass data both qualitatively and quantitatively.

As suggested by Yildiz Durak (2020), integrating CT into mathematics instruction may afford students opportunities to refine their logical thinking and problem-solving abilities. A total of 112 participants will be selected for the research, which will take place at a local EMI DSS primary school in Hong Kong, contingent upon the school's consent to participate and the availability of necessary resources to facilitate the study. The participant roster includes a principal, four STEAM curriculum coordinators, and one hundred and nineteen sixth-grade students. The research will be conducted with the collaboration of the teachers and students at the school.

The conclusions drawn from this study hold significant implications for scholars, educators, and policymakers both in Hong Kong and internationally. The findings will contribute to the formulation of policies and practices related to CTE and ME and will enrich the ongoing discourse on optimal approaches for preparing students for the digital age. The study results may be disseminated through presentations, publication in academic journals, and engagement with decision-makers, educators, and other stakeholders. Ultimately, this study will offer valuable insights into incorporating CT into the mathematics curriculum for Hong Kong's Primary 6 students.

The primary objectives of the research are not only to appraise the efficacy of integrating CT into ME, with a focus on enhancing students' academic performance and cultivating interest in ME, but also to examine the attitudes and perspectives of both teachers and students regarding the inclusion of CTE within ME.

# 2. LITERATURE REVIEW

## 2.1 Theoretical Perspectives

CT integration into ME has drawn more attention in recent years (Bocconi et al., 2016). The increased use of technology in many facets of life has led experts to identify CT as an essential ability for the 21st century. CT is a problem-solving strategy that entails applying computational approaches to assess and solve issues (Voogt et al., 2015). Constructivism is one theoretical framework that encourages the use of CT in mathematics teaching. Through experiences and interactions with their environment, learners actively develop their own knowledge and understanding, according to this viewpoint (Borg, 2016; Steffe & Ulric, 2020). By encouraging students to utilize technology to investigate and understand mathematical topics, the integration of CT into ME may be seen as a way to engage students in active learning and problem-solving. The idea of "computational participation" is another theoretical framework that backs the use of CT in mathematics teaching (Kafai, 2016). This viewpoint emphasizes the significance of participating in the invention and development of technology as well as utilizing it to address issues (Resnick et al., 2009). Students may get a greater grasp of how technology works and how it can be utilized to generate answers to issues in the real world by incorporating CT into their mathematical curriculum. Additionally, the inclusion of CT in math instruction is consistent with STEAM education's guiding principles, which place a strong emphasis on combining math with science, technology, engineering, arts, and mathematics (Pears et al., 2019). Students may acquire the abilities required to engage in the increasingly technology and data-driven world and to help create new technologies and ideas by incorporating CT into mathematics instruction (National Research Council, 2011). Several theoretical stances, including constructivism, computational involvement, and STEAM education, promote the use of CT into mathematical teaching. These viewpoints stress the value of problem-solving, active learning, and technical literacy, all of which may be achieved via the use of CT into mathematics instruction. Students may benefit from greater preparation for the possibilities and difficulties of the digital era by doing this.

There are several theoretical stances on this matter from a variety of academic fields, such as education, computer science, and cognitive psychology. The cognitive load hypothesis postulates that the amount of mental work required to acquire new information may have an impact on how effective learning is (Sweller, 1994). CT may be used into ME to assist students grasp difficult mathematical ideas by providing them with tools and methods that do so. As a consequence, learning outcomes may be improved, and information retention may increase (Sweller, 2011). According to the Cognitive Load Theory (CLT), learning is influenced by the quantity of information or mental effort needed to comprehend new knowledge since working memory has a finite capacity. The learning process becomes challenging and unproductive if the working memory capacity cannot handle the cognitive burden of learning a new notion.

By giving students the skills and techniques to simplify complicated mathematical topics, CT may be included into mathematics instruction to assist reduce the cognitive burden. With the help of interactive simulations or data sets, students can use CT to visualize mathematical concepts and come up with new ideas and solutions. CT entails breaking a problem down into smaller, more manageable pieces, identifying patterns and relationships, and developing algorithms to solve the problem. They may increase their comprehension of abstract mathematical ideas in this way, which will enhance their learning and memory of what they have learned. Critical thinking and problem-solving abilities, which are crucial in today's environment, may be developed by kids using CT. These abilities may help pupils improve their capacity for learning, thinking, and problem-solving in a variety of diverse contexts. Reduced cognitive load, improved learning outcomes, and the development of critical thinking and problem-solving abilities—all of which are crucial for success in the contemporary world—can all be achieved by adding CT into mathematics instruction (Doleck et al., 2017).

## 2.2 Empirical Perspectives

Due to the growing use of technology in many facets of life, the incorporation of CT into ME has attracted a lot of attention recently. The inclusion of CT in mathematics teaching has received support from empirical studies. According to a 2009 research by Resnick et al. (2009), students' problem-solving skills significantly improved when they were taught utilizing CT-based activities as opposed to when they were taught using conventional techniques. The research proved that CT has the ability to improve pupils' problem-solving abilities. Similar to this, Voogt et al. (2015) discovered that adding CT to math lessons helped students develop their logical reasoning and critical thinking abilities. According to the research, pupils were better able to recognize difficulties and use logical thinking to come up with answers when CT-based exercises were included in mathematics lessons. These results show how CT may help students develop the analytical and problem-solving abilities necessary for success in the digital era. The motivation and involvement of pupils have been observed to increase as a result of the incorporation of CT into mathematics teaching. According to a research by Bers et al. (2014), the use of CT in mathematics instruction boosted student interest and engagement. The research emphasized how CT has the ability to foster more interactive and collaborative learning environments, which may improve students' academic and social growth.

However, incorporating CT into arithmetic instruction may sometimes be difficult. According to Saad (2020), a considerable change in pedagogy from a teacher-centered to a student-centered approach was necessary to successfully integrate CT into mathematics teaching. The necessity for teacher professional development in CT and its incorporation into mathematics instruction was also noted by the research. These results indicate that successful implementation of CT-based activities in mathematics instruction needs careful preparation and support for teachers. To further promote the integration of CT into ME, Gadanidis et al. (2017) underlined the need for suitable technology tools and resources. In addition to using digital tools, the research indicated that tactile manipulatives like blocks and puzzles might help pupils strengthen their CT abilities. In order to assist the integration of CT into mathematics instruction, the research emphasizes the value of having a range of tools and resources available. The use of CT in ME is supported by empirical research, which also identifies its potential and problems. The improvement of students' problem-solving abilities, critical thinking, and motivation has been linked to CT; nevertheless, its implementation calls for a change in pedagogy, professional development for teachers, and the use of the right technology tools and resources. To prepare students for the benefits and difficulties of the digital era, educators must carefully plan and promote the integration of CT into mathematics instruction.

The effects of incorporating CT into a middle school mathematics curriculum were the subject of a different research by Grover and Pea (2013). According to the research, pupils' mathematical aptitude and problem-solving abilities increased as a result of the incorporation of CT. The research showed that, in addition to improving students' problem-solving abilities, CT has the potential to improve students' mathematical abilities. In addition, Sondakh et al.'s (2020) research discovered that students' teamwork and communication skills improved as a result of the use of CT in mathematics instruction. According to the research, CT has the potential to foster a more collaborative and interesting learning environment, which may benefit students' social and intellectual growth.

Moreover, a research by Herro et al. (2021) discovered that the inclusion of CT in mathematics instruction may foster equality in the classroom. A more inclusive and stimulating learning environment was produced by the use of CT-based activities, according to the research. This may support efforts to close achievement disparities and advance equality in the classroom. But there are also difficulties with incorporating CT into math teaching. According to research by Marcelino et al. (2018), teachers may find it difficult to make the transition from using conventional teaching approaches to ones that are more student-centered and technology-oriented when integrating CT into mathematics instruction. According to the research, in order to effectively include CT into their lessons, teachers must have the necessary knowledge and abilities. They must also make sure that students have access to the right technology resources and tools. Gadanidis et al. (2017) looked at the use of physical manipulatives, including puzzles and blocks, to enhance students' development of CT abilities in mathematics instruction in a different research. In addition to using digital tools, the research discovered that using physical manipulatives may help children build CT abilities including pattern identification, algorithmic reasoning, and deconstruction. The research also emphasized how crucial it is to create instructional activities that let students switch between using physical and digital resources to promote their learning. Similar to this, ML et al. (2019)'s research examined how robots may be used to include CT into high school mathematics instruction. According to the research, using robots enabled students to participate in real-world problem-solving tasks that called for the use of CT abilities including algorithmic thinking, pattern identification, and abstraction. The research also emphasized the significance of teacher professional development in robotics and CT, as well as the need for suitable technological resources to assist the integration of CT into mathematics teaching.

Moreover, Charsky and Mims (2008) examined the effects of incorporating CT into a college-level mathematics course. The research indicated that adding CT to the curriculum increased student interest and engagement while also fostering the growth of higher order thinking abilities including decision-making, problem-solving, and critical thinking. The research also noted the need for CT teacher professional development and its incorporation into mathematics instruction, as well as the requirement for suitable technology tools to aid in students' learning. Grover and Pea (2013) did another research in which they looked at the usage of mobile devices to include CT into the teaching of middle school mathematics. The research showed that students could participate in real-world problem-solving tasks that required the use of CT abilities including algorithmic thinking, pattern identification, and abstraction while using mobile devices like tablets and smartphones. The research also emphasized the necessity for proper teacher professional development in CT and mobile learning, as well as the need for suitable technology tools to assist students' learning. Additionally, a research by Khine(2018) looked at the effects of incorporating CT into the teaching of mathematics in elementary schools. The research discovered that using digital games enabled students to participate in real-world problem-solving tasks that called on the use of CT abilities including algorithmic thinking, pattern recognition, and abstraction. The survey also found a need for CT teachers to undergo professional development, for digital games to be included in math lessons, and for the right technology tools to promote kids' learning.

Research of how digital storytelling may be used to include CT into the teaching of primary school mathematics (Kordaki & Kakavas, 2017; Parsazadeh et al., 2021). According to the research, students were able to participate in real-world problem-solving tasks that called for the use of CT abilities including algorithmic thinking, pattern identification, and abstraction while using digital storytelling. The research also emphasized the significance of CT teacher professional development and the incorporation of digital storytelling into mathematics instruction, as well as the need for suitable technology tools to enhance students' learning.

As a conclusion, empirical evidence supports the incorporation of CT into ME using a variety of strategies, including robotics, physical manipulatives, mobile devices, digital games, and digital storytelling. The study outlines the advantages of incorporating CT into mathematics instruction, including enhanced problem-solving skills, critical thinking, logical reasoning, student motivation, and engagement.

### 2.3 Theoretical Framework

CT, ME, and problem-based learning (PBL) are three important topics on which this study's theoretical framework is founded. Given the growing use of technology in many facets of life, it has been determined that the incorporation of CT into mathematics instruction is a critical skill for the 21st century. CT is a method of problem-solving that makes use of computer methods for issue analysis and resolution. The development of pupils' logic and problem-solving abilities depends heavily on their ME (Ersoy, 2016). By giving students real-world, purposeful learning opportunities, PBL has been shown to be a successful method for getting them involved in problem-solving and active learning. PBL is a method of instruction wherein students collaborate to find solutions to challenging real-world situations (Barber et al., 2015). Students may benefit from real-world, authentic learning experiences that are applicable to their daily lives when CT is included into mathematics teaching via PBL (Gao et al., 2019). Students may acquire problem-solving abilities as well as a better comprehension of how technology works and how it can be utilized to produce answers to issues in the real world by incorporating CT into mathematics instruction. PBL gives students the chance to use their CT and math abilities to solve real-world issues, which boosts engagement and motivation.

The constructivist tenets, which highlight the value of problem-solving and active learning, have an influence on the theoretical foundation for this research as well. This viewpoint claims that learning happens when individuals actively create their own knowledge and understanding via experiences and interactions with their surroundings (Walden et al., 2013). By encouraging students to utilize technology to investigate and understand mathematical topics, the integration of CT into ME via PBL may be considered as a tool to engage students in problem-solving and active learning. The STEAM education concepts, which stress the fusion of science, technology, engineering, arts, and mathematics, also serve as a basis for the theoretical framework for this research. Students may get the skills essential to engage in the increasingly technology and data-driven world as well as contribute to the creation of new technologies and inventions by incorporating CT into mathematics teaching via PBL. This study's theoretical foundation is built on the confluence of PBL, CT, and ME. Through the use of PBL, CT may be included into mathematics instruction to provide students real-world, applicable learning experiences that also help them to improve their technical literacy and problem-solving abilities. The constructivist and STEAM educational philosophies, which place a strong emphasis on problem-solving and active learning, as well as the fusion of these subjects, serve as the theoretical foundation for the framework.

The notion of "mathematical problem-solving," which stresses the significance of problem-solving as a basic part of mathematics (Ersoy, 2016), is another significant theory in relation to ME. Students may participate in technology-based problem-solving exercises by introducing CT into their math lessons, which will help them build their problem-solving abilities and their capacity to apply mathematical ideas in practical contexts. Both the field of CTE and the field of ME may benefit from the "socio-cultural learning" paradigm. According to Vygotsky and Cole (1978), this theory stresses the significance of social and cultural circumstances in the learning process. Students may participate in group problem-solving activities that employ technology when CT is included into mathematics instruction, helping them to improve their ability to collaborate with others and effectively convey their ideas. The term "mathematics anxiety," which refers to the unfavorable emotions and sentiments connected to mathematics (Richardson and Suinn, 1972), is another crucial idea in relation to ME. Students may participate in problem-solving exercises that are more dynamic and engaging by adding CT into mathematics lessons, which may help them feel less anxious about arithmetic and spark their interest in it. The idea of "transfer of learning" is pertinent to both ME and CTE. According to Bransford et al. (2000), transfer of learning is the process of using previously acquired information and abilities in new contexts. Students may acquire transferable problem-solving abilities that can be used in a number of real-world scenarios by adding CT into their mathematics curriculum.

The notion of "computational literacy," which highlights the significance of comprehending the basic concepts and principles of computer science, is another pertinent theory linked to CTE (Wing, 2006). Students may learn computer literacy abilities that can be used in a number of professions by introducing CT into mathematics instruction, improving their employability and preparing them for the digital age. An abstraction is a concept in both CTE and ME. The process of abstraction is seeing similarities across many issues or circumstances in order to create overarching guidelines or techniques that may be used to address those issues. Abstraction in CTE refers to the recognition of trends and generalizations across various computer jobs (Hunsaker, 2020). Finding mathematical patterns and generalizations is a component of abstraction in ME.

Another key idea in the teaching of both CT and mathematics is algorithmic thinking. The process of solving issues using systematic and logical processes is known as algorithmic thinking (Kalelioglu et al., 2016). The creation of algorithms and the usage of flowcharts to depict those algorithms are both aspects of algorithmic thinking that are covered in CTE. Algorithmic thinking in ME refers to the use of processes and algorithms to resolve mathematical puzzles. Finally, both CTE and ME may benefit from the notion of creativity. Creativity in CTE refers to the creation of original, creative solutions to issues. The creation of novel mathematical ideas and methods, as well as the use of mathematical ideas to address practical issues, are all examples of creativity in ME.

Finally, constructivism, problem-solving, abstraction, algorithmic thinking, and creativity are only a few of the theories and ideas that are shared by CTE and ME. These theories and ideas provide a solid framework for the incorporation of CT into ME and emphasize the value of CT skill development for fostering students' social and intellectual growth in the digital era. By relying on these theories and ideas, educators may successfully incorporate CT into mathematics instruction and get students ready for the possibilities and difficulties of the twenty-first century.

### 2.3.1 Computational thinking

The concept of CT was first introduced by Seymour Papert in the 1980s, as Papert explored the potential of computers to transform education and learning (Papert, 1980). However, the term gained widespread recognition and prominence following Jeannette Wing's seminal article, "Computational Thinking" published in 2006. Wing (2006) defined CT as a set of problem-solving skills and techniques that involve the application of computer science principles and concepts, even in the absence of direct computer use.

Several studies and reports have elaborated on the key elements of CT, which include problem decomposition, pattern recognition, abstraction, and algorithmic thinking (Barr & Stephenson, 2011; Grover & Pea, 2013; Rowe et al., 2017; Selby & Woollard, 2013; Shute et al., 2017; Wing, 2008; Yasin & Nusantara, 2023).

Problem decomposition is the process of breaking down complex problems into smaller, more manageable parts. This skill is essential for tackling intricate tasks and systematically addressing challenges (Denning, 2009). Lye & Koh (2014) emphasized the importance of problem decomposition in fostering students' ability to dissect problems and develop a deeper understanding of the underlying structure.

Pattern recognition entails identifying similarities, trends, and recurring elements within problems. Recognizing patterns allows individuals to make predictions, draw inferences, and establish connections between seemingly unrelated concepts (Barr & Stephenson, 2011). Curzon et al. (2014) argued that pattern recognition is a critical skill for problem-solving and decision-making across various disciplines.

Abstraction is the process of simplifying problems by removing unnecessary details and focusing on essential aspects. Abstraction enables individuals to generalize and transfer knowledge from one context to another (Grover & Pea, 2013). Weintrop et al. (2016) asserted that abstraction is a fundamental aspect of CT, as it allows for the efficient representation and manipulation of complex information.

Algorithmic thinking involves developing step-by-step procedures or rules to solve problems systematically and efficiently. Algorithms are the basis for computer programs and underpin the functioning of digital technologies (Wing, 2008). Lee et al. (2011) highlighted the importance of algorithmic thinking in fostering students' ability to create and analyze algorithms for various tasks.

The relationship between CT and computer science has been extensively discussed in the literature. CT serves as the foundation for computer science concepts such as programming, data structures, and algorithm design (Wing, 2006). Denning (2009) posited that CT is an essential skill for computer scientists, as it enables them to develop effective algorithms and software systems.

Moreover, CT is not limited to computer science but extends to other domains as a general problem-solving skill (Yadav et al., 2014). Guzdial (2008) argued that CT should be viewed as a universal literacy, essential for navigating an increasingly digital world.

### 2.3.2 The relationship between computational thinking education and 21st-century competencies

While CTE is indeed crucial for developing problem-solving skills, it also fosters the growth of generic skills in students that can be applied to various fields and disciplines, which are identified as the 21-st century competencies. These generic skills, often referred to as transferable skills, include critical thinking, collaboration, communication, and creativity, among others (National Research Council, 2012).

Critical thinking is a vital skill that enables students to analyze information, evaluate evidence, and make reasoned judgments. CTE encourages students to approach problems systematically, identify underlying causes, and develop well-founded solutions (Kules, 2016). This skill can be applied to various disciplines and real-life situations, equipping students with the ability to make sound decisions based on logic and reason. Collaboration and teamwork are essential skills fostered by CTE. As students work together on CT projects, they learn to share ideas, listen attentively, and contribute effectively to the group's success. These skills are vital in today's interconnected world, where professionals often collaborate with colleagues from diverse backgrounds to solve complex problems.

Communication skills are also honed through CTE. Students must articulate their thoughts clearly, both in writing and verbally, as they work with peers and present their ideas. Effective communication is crucial in virtually every career and social situation, enabling individuals to express themselves, build relationships, and resolve conflicts (Tang et al., 2020). Israel-Fishelson and Hershkovitz (2022) mentioned that creativity is another important skill developed through CTE. By experimenting with different solutions, students learn to think outside the box and come up with innovative ideas. This skill is highly valued in many industries, as it allows individuals to adapt to change, generate new possibilities, and find unique approaches to challenges.

Moreover, CTE can help students develop important 21st-century competencies that are essential for success in today's rapidly changing world (Juškevičienė & DagienĖ, 2018). These competencies include critical thinking, collaboration, and creativity.

Students get the ability to approach issues systematically and logically by disassembling them into manageable parts that can be studied and addressed via CT instruction (Chukwuyenum, 2013). Students must be able to recognize the essential elements of an issue and choose the most effective approach to solving it, which calls for the use of critical thinking abilities. Working together with others is another frequent component of CTE, which promotes the growth of students' teamwork and collaboration abilities. Additionally, a key component of CTE is the development of original solutions to issues, which calls for imagination and the capacity for creative problem-solving. Students improve their innovative problem-solving skills, which can be used in a number of circumstances, by employing CT to solve challenges. In addition to these skills, CTE may aid students in acquiring digital literacy abilities, such as the capacity to utilize technology skillfully and morally (Tsai er al., 2021; Yadav et al., 2017). These abilities are becoming more and more crucial for success in both academic and professional situations as technology becomes more and more relevant in many sectors.

Overall, fostering 21st-century skills via CT instruction may help students be ready for success in a world that is changing quickly. Students may improve their readiness for the difficult problems of the 21st-century by cultivating their critical thinking, collaboration, creativity, and digital literacy abilities. This description emphasizes the need for higher-order abilities, who asserted that CT in mathematics encompasses these higher-order skills: semiotic representations, pattern identification, and model construction (Barcelos & Silveira, 2012; Barcelos et al., 2018; Vallance & Towndrow, 2018).

In addition, CTE is essential for preparing pupils for employment in STEAM industries in the future (Grover et al., 2015; Grover, 2017) . In a variety of vocations, such as software development, data analysis, engineering, and scientific research, CT ideas and abilities are becoming more and more in demand (Judy & D'amico, 1997). Schools may assist to guarantee that students are prepared for the demands of the contemporary workforce by incorporating CTE into already-existing courses. By giving students a strong foundation in problem-solving abilities, CTE helps them become ready for future professions in STEAM industries. In CT, students learn to discover patterns and connections in complicated issues, break them down into smaller, more manageable pieces, and then use their knowledge of coding and programming to create solutions. These abilities are crucial in a variety of STEAM occupations in the 21st-century since they often demand people to tackle challenging issues and come up with novel solutions.

### 2.3.3 Effective computational thinking education

The acquisition of CT skills has become increasingly important in the digital age, necessitating effective approaches for teaching these skills to students (Wing, 2006). A variety of teaching strategies have been proposed in the literature to facilitate the learning of CT skills. Some of these strategies include scaffolding, cooperative learning, active learning, and more.

Scaffolding involves providing students with support and guidance as they engage in challenging tasks, gradually removing the support as they become more competent (Gibbons, 2002). Scaffolding has been shown to be effective in teaching CT concepts, as it enables students to build their skills incrementally and gain confidence in their abilities (Angeli & Valanides, 2020; Basu et al., 2017).

Encouraging students to work together on CT tasks can foster a collaborative learning environment, where students learn from and support one another (Vygotsky & Cole, 1978). Research has demonstrated that peer collaboration can enhance students' understanding of CT concepts and improve their problem-solving skills (De Jesús & Silveira, 2021; Saad, 2020).

Active learning approaches, which involve students actively engaging with the material through hands-on experiences, have been shown to be effective in teaching CT skills (Prince, 2004). Examples of active learning strategies include problem-solving exercises, project-based learning, and inquiry-based learning (Cattaneo, 2017).

In addition, several pedagogical approaches have been identified in the literature as effective in teaching CT skills. Firstly, unplugged Activities. Unplugged activities are non-digital, hands-on tasks that help students develop CT skills without the use of computers (Brackmann et al., 2017). These activities often involve physical manipulation, role-play, or the use of tangible objects to represent computational concepts. Unplugged activities have been praised for their potential to engage diverse learners and build foundational CT skills (Caeli & Yadav, 2020; Curzon et al., 2014). Secondly, visual Programming Languages. Visual programming languages, such as Scratch and Blockly, allow students to create programs using drag-and-drop blocks, making programming more accessible and engaging (Resnick et al., 2009). Research has shown that visual programming languages can effectively support the development of CT skills by providing an engaging and accessible platform for students to experiment with programming concepts (Koh et al., 2010). Thirdly, Project-Based Learning (PBL). PBL is an instructional approach that encourages students to engage in authentic, real-world problem-solving activities (Kokotsaki et al., 2016). PBL has been identified as a promising pedagogical approach for teaching CT because it fosters students' ability to apply problem-solving strategies and computer science concepts in various contexts (Cui et al., 2023; Shin et al., 2021). Last but not least, the Technological Pedagogical Content Knowledge (TPACK) approach has also been recognized as one of the most effective methods for promoting CTE.

### 2.3.4 Technological pedagogical content knowledge approach

The TPACK framework, introduced by Mishra and Koehler (2006), emphasizes the integration of three key aspects of teaching: technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK). TPACK acknowledges the interplay between these components, which are essential for effective teaching in the digital age.

Several studies have highlighted the relevance and applicability of the TPACK framework in CT education. For instance, Kong and Lai (2021) argue that TPACK can provide a comprehensive understanding of the knowledge and skills required by educators to teach CT effectively. Furthermore, Yildiz Durak et al. (2022) propose that the TPACK framework can be adapted to address specific CT concepts and skills, thereby enhancing its effectiveness in CT education.

Research studies have provided empirical evidence of the effectiveness of the TPACK approach in CT education. In a study conducted by Mäkitalo et al. (2019), pre-service teachers who received TPACK-based CT training demonstrated improvements in their CT skills and self-efficacy. Similarly, Kitalo et al. (2019) found that a TPACK-based intervention significantly increased pre-service teachers' CT capabilities and pedagogical knowledge.

Moreover, the TPACK approach has been shown to be effective in promoting CT education across various disciplines. For example, Syukri et al. (2020) revealed that the integration of the TPACK framework in STEM Education led to improved CT competencies among learners. In addition, Helsa and Juandi (2023) reported positive effects of TPACK-based CT instruction on students' problem-solving skills and academic achievement in a social sciences context.

Implementing the TPACK approach in CT education offers several benefits. First, it provides a comprehensive framework that considers the interdependencies between technology, pedagogy, and content, which are critical for effective CT instruction (Mishra & Koehler, 2006). Consequently, it helps educators develop a holistic understanding of how to incorporate CT in the teaching and learning process.

Second, the TPACK framework supports the development of teacher competencies required for CT education. By focusing on the intersection of TK, PK, and CK, the framework enables teachers to develop a deeper understanding of CT concepts, pedagogical strategies, and technological tools (Voogt et al., 2015).

Lastly, the TPACK approach promotes the integration of CT across various disciplines, fostering interdisciplinary learning and enhancing the overall quality of education (Tondeur et al., 2017).

### 2.3.5 Computational thinking in education

CT has emerged as a vital skill for the 21st century, with significant implications for education across various disciplines (Wing, 2006). The importance of incorporating CT into the K-12 curriculum has been widely acknowledged in recent literature (Barr & Stephenson, 2011; Grover & Pea, 2013). Educators and researchers argue that CT skills are essential for preparing students for a digitally driven world, regardless of their chosen career paths (Yadav et al., 2014).

Several national and international educational initiatives have been implemented to promote the integration of CT into K-12 curricula. For instance, the Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE) have developed standards and guidelines for teaching CT across grade levels. Additionally, countries such as the United Kingdom and Australia have introduced mandatory computer science curricula that emphasize CT (Falkner et al., 2019; Passey, 2017).

### 2.3.6 Challenges in promoting computational thinking education

While the importance of CT in education has been widely recognized (Wing, 2006), several challenges persist in promoting and implementing CTE effectively.

A key challenge in promoting CTE is ensuring that teachers are adequately prepared to teach CT concepts and skills (Yadav et al., 2014). Many educators lack the necessary background in computer science or feel unconfident in their ability to teach CT, which ultimately hinders the effective implementation of CTE in the classroom (Grover & Pea, 2013). To address this issue, research has emphasized the importance of providing professional development opportunities for teachers, such as workshops, online courses, and in-service training programs (Koh et al., 2014).

Another challenge in promoting CTE is the integration of CT concepts and skills into existing curricula (Voogt et al., 2015). While some countries have introduced standalone computer science courses, many educators argue that CT should be integrated across various subject areas to promote interdisciplinary learning (Bocconi et al., 2016). However, the integration of CT into diverse subjects can be complex and requires careful planning, collaboration, and the development of appropriate learning materials and activities (Mannila et al., 2014).

Assessing students' CT skills poses a significant challenge for educators and researchers alike. Traditional assessment methods, such as standardized tests and written exams, may not adequately capture the full range of CT skills, which include problem-solving, abstraction, and algorithmic thinking (Denning, 2009). Consequently, researchers have called for the development of novel assessment approaches that align with the unique characteristics of CT, such as performance-based assessments, rubrics, and digital portfolios (Brackmann et al., 2017).

Promoting equitable access to CTE for all students, regardless of their socioeconomic background, gender, or ethnicity, is another significant challenge (Sáez-López et al., 2016). Research has highlighted the underrepresentation of certain groups, particularly girls and students from low-income backgrounds, in computer science and CTE (Cheryan et al., 2017). To address this issue, researchers and practitioners have emphasized the importance of creating inclusive learning environments, providing targeted support and resources, and promoting awareness of the benefits of CTE for all students (Master et al., 2017).

### 2.3.7 Teacher professional development in computational thinking education

The importance of teacher preparation for CT teaching cannot be overstated, as many teachers may not be conversant with CT principles (Li, 2021).

Various PD opportunities have emerged to support teachers in developing their CT knowledge and pedagogical skills. These opportunities can take the form of face-to-face workshops, online courses, in-service training programs, or conferences (Koh et al., 2010). While the availability of PD opportunities varies across countries and regions, there has been a notable growth in online PD resources, such as the Google Computer Science for High

School (CS4HS) program and the Code.org professional learning program, which can be accessed by educators globally.

Despite the increasing availability of PD opportunities, the extent of teacher participation in CT-specific PD remains relatively low and several challenges remain. Studies have reported that many teachers feel unprepared to teach CT due to their limited background in computer science and lack of confidence in their CT knowledge and skills (Yadav et al., 2014). Moreover, limited time, resources, and competing priorities within the education system can hinder teacher engagement in PD programs. Also, many teachers face constraints on their time and resources, which can make it difficult for them to participate in PD programs (Chang & Peterson, 2018). To address this issue, research has suggested that PD programs should be designed to be flexible, accessible, and cost-effective, allowing teachers to engage with PD in ways that fit their needs and circumstances (Hsu et al., 2019). Moreover, some teachers may be resistant to the idea of incorporating CT into their teaching, particularly if they do not have a background in computer science or feel that CT is not relevant to their subject area (Grover & Pea, 2013). To overcome this resistance, PD programs should emphasize the interdisciplinary nature of CT and provide teachers with concrete examples of how CT can be integrated into their existing curricula (Yadav et al., 2017).

### 2.3.8 Mathematics education in Hong Kong

ME in Hong Kong has received significant attention due to the region's consistently high performance in international assessments such as the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) (Chen, 2014; Hopfenbeck et al., 2018). The key features of Hong Kong's ME system, including curriculum design, teaching and assessment practices, teacher professional development, and the challenges faced in ME were examined.

The mathematics curriculum in Hong Kong is designed to develop students' mathematical literacy, problem-solving skills, and positive attitudes towards mathematics (Curriculum Development Council, 2017a). The curriculum is divided into two key stages in primary education, from primary 1 to 3 and primary 4 to 6 respectively, with the former focused on building foundational skills and the latter on deepening students' understanding of more advanced mathematical concepts (Curriculum Development Council, 2017b).

The curriculum is organized around five strands in the first two key stages, which are, number, algebra, measures, shape and spaces, and data handling (Curriculum Development Council, 2017b). Additionally, the curriculum emphasizes the integration of technology, such as calculators and computer software, to enhance students' learning experiences and support the development of their mathematical reasoning and communication skills (Curriculum Development Council, 2017a).

Hong Kong's ME is characterized by a combination of traditional and contemporary teaching methods. Teachers often use direct instruction, drilling, and practice exercises to build students' procedural fluency and mastery of mathematical concepts (Ng & Rao, 2008). However, there has been a growing emphasis on incorporating more student-centered approaches, such as inquiry-based learning, collaborative problem-solving through using a dynamic mathematics software, Geogebra and the use of real-life contexts to make mathematics more relevant and engaging for students (Poon, 2018).

Despite the high performance of Hong Kong students in international mathematics assessments, there is growing concern about the issue of low learning motivation in ME (Leung, 2002; OECD, 2014).

### 2.3.9 Effective approach for integrating computational thinking education into existing curricula

One effective approach to integrating CTE is through interdisciplinary collaborations that embed CT concepts and practices within various subject areas (Yadav et al., 2017). By connecting CT to core subjects, such as mathematics, science, and social studies, students can better understand the relevance and applicability of CT skills in their daily lives and future careers (Bocconi et al., 2016). Moreover, interdisciplinary approaches promote a deeper understanding of subject-specific content and foster the development of critical thinking and problem-solving skills (Lye & Koh, 2014).

Furthermore, selecting appropriate CT tools and resources is crucial. Among the myriad options available, such as coding platforms, programming languages, and robotics kits, it is vital to choose tools and materials that align with the desired learning outcomes (Perković et al., 2010). Additionally, ensure that the selected resources are suitable for the students' age and skill level.

Next, assessing students' CT skills is crucial for understanding the effectiveness of CT integration efforts and identifying areas for improvement (Grover & Pea, 2013). Assessments should be designed to measure students' ability to apply CT concepts and practices in diverse contexts, rather than merely assessing their knowledge of specific programming languages or tools (Barr & Stephenson, 2011). Multiple assessment methods, such as formative assessments, performance assessments, and student self-assessments, can provide a comprehensive picture of students' CT competencies and inform future instructional decisions (Lye & Koh, 2014).

2.3.10 Introduction to integrating computational thinking into mathematics education

Integrating CT into ME can help students develop a deeper understanding of mathematical concepts, enhance problem-solving abilities, and foster creativity and resilience (Barr & Stephenson, 2011). CT and mathematical thinking share several key characteristics, such as abstraction, pattern recognition, algorithmic thinking, and the ability to decompose problems into smaller, more manageable components (Weintrop et al., 2016). By integrating CT into ME, educators can leverage these commonalities to help students develop a more nuanced understanding of mathematical concepts and practices (NCTM Research Committee, 2018). Moreover, CT can facilitate the application of mathematical knowledge in diverse, real-world contexts, fostering students' ability to transfer skills across domains (Yadav et al., 2017).

Integrating CT in ME involves incorporating CT concepts and practices within existing mathematical curricula (Bocconi et al., 2016). This can be achieved through the development of interdisciplinary units or lessons that connect CT skills, such as algorithmic thinking and data representation, with mathematical content areas, such as algebra, geometry, and statistics (Weintrop et al., 2016). By embedding CT within the mathematics curriculum, educators can create meaningful learning experiences that demonstrate the relevance of both CT and mathematical skills for students' future careers and personal lives (NCTM Research Committee, 2018).

Effective pedagogical strategies for integrating CT in ME include PBL, collaborative learning, and the use of digital tools and platforms (Barr & Stephenson, 2011). PBL encourages students to apply CT skills to solve complex, authentic mathematical problems, fostering deep learning and the development of critical thinking abilities (Lye & Koh, 2014). Collaborative learning environments promote the sharing of diverse perspectives and approaches to problem-solving, enhancing students' understanding of CT and mathematical concepts (Grover & Pea, 2013). Lastly, digital tools and platforms, such as programming languages and visualization software, enable students to explore mathematical ideas through computational methods, bridging the gap between CT and ME (Weintrop et al., 2016).

### 2.3.11 Appropriate tools and resources to support integrating computational thinking in mathematics education

Programming environments are essential tools for integrating CT in ME, as they allow students to explore mathematical concepts through computational methods (Weintrop et al., 2016). These environments enable students to engage in algorithmic thinking, pattern recognition, and abstraction while applying mathematical concepts to solve real-world problems (Lye & Koh, 2014). In a research published in 2017, Gadanidis et al. looked at how to employ the right technological resources and tools to promote the incorporation of CT into mathematics teaching. The goal of the research was to find practical methods for enhancing the development of CT skills in mathematics instruction via the use of technological resources, both physical and digital. According to the study's results, in addition to using digital tools, tactile manipulatives like blocks and puzzles may help pupils strengthen their CT abilities. The study identified three design principles for the efficient use of technology tools in ME, which are the tool should be easily accessible and manipulable by students, the tool should allow for exploration and experimentation, and the tool should be simply incorporated into classroom activities. The results demonstrated that using the right technological resources and tools may boost students' interest in learning mathematics and motivation while also assisting in the development of CT abilities. Examples of blockly programming platforms that are suitable for primary education that support integrating CT into ME include Scratch, Micro:bit, CoSpaces Edu, App Inventor, and VinciBot, which offer varying levels of complexity and accessibility for students with diverse backgrounds and experiences (Grover & Pea, 2013).

Scratch is a widely used block-based programming platform that allows students to create interactive projects, stories, and games while developing CT skills (Fagerlund et al., 2021; Resnick et al., 2009; Stewart & Baek, 2023; Zhang & Nouri, 2019). In the context of ME, Scratch can be employed to create simulations, visualizations, and interactive activities that help students explore mathematical concepts such as geometry, algebra, and number sense (Grover & Pea, 2013). By manipulating visual blocks, students can engage in algorithmic thinking, pattern recognition, and abstraction, which form the core components of CT (Lye & Koh, 2014). Scratch also promotes collaboration and communication, allowing students to share their projects and learn from their peers (Brennan & Resnick, 2012).

The Micro:bit is a small, programmable microcontroller that can be programmed using a block-based language, making it an accessible tool for integrating CT in ME (Shahin et al., 2022; Syamsudin & Riza, 2023). Students can develop CT skills by creating and testing algorithms to control the Micro:bit's sensors and actuators, applying mathematical concepts such as variables, functions, and coordinate systems in the process (Pech & Novák, 2020; Voštinár & Knežník, 2020). The hands-on nature of the Micro:bit encourages experimentation and iteration, fostering the development of problem-solving skills and resilience in the face of challenges (Bocconi et al., 2016).

CoSpaces Edu is a virtual reality (VR) platform that enables students to create and explore three-dimensional (3D) environments using Blockly-based programming (IM, 2017; Lunding et al., 2022). In the context of ME, CoSpaces Edu can be used to explore geometric shapes, spatial relationships, and transformations through immersive experiences that promote deep understanding (NCTM Research Committee, 2018). By developing algorithms to manipulate virtual objects, students can engage in CT practices such as decomposition, generalization, and evaluation (Yadav et al., 2017). CoSpaces Edu also encourages collaboration, allowing students to work together on projects and share their experiences with others.

App Inventor is a block-based programming platform that enables students to create mobile applications for Android devices, promoting the development of CT skills in the process (Morelli et al., 2011; Patton et al., 2019). In the context of ME, App Inventor can be used to develop educational apps that teach mathematical concepts, such as number sense, algebra, and geometry (Liu et al., 2013; Pérez-Jorge & Martínez-Murciano, 2022; Turbak et al., 2014; Voštinár, 2017). Students can apply CT practices, such as abstraction and algorithmic thinking, to design user interfaces and implement mathematical features within their apps (Patton et al., 2019).

VinciBot is a block-based programming platform designed for controlling educational robots, offering a tangible and engaging approach to developing CT skills. In the context of ME, VinciBot can be used to create mathematical challenges and activities that involve programming robots to navigate through mazes, solve puzzles, or perform geometric transformations. These activities enable students to apply CT practices such as pattern recognition, decomposition, and generalization while deepening their understanding of mathematical concepts. VinciBot also promotes collaboration and communication, as students can work together on tasks and share their solutions with others.

### 2.3.12 The significance of integrating computational thinking into mathematics education

According to Barr and Stephenson (2011), integrating CT into ME can enhance students' problem-solving skills and deepen their understanding of mathematical concepts by engaging them in computational activities and tasks. By using algorithmic thinking, pattern recognition, and abstraction, students can break down complex problems into manageable components, identify relevant patterns, and generalize solutions to a broader range of problems (Lye & Koh, 2014). This process not only strengthens their mathematical reasoning abilities but also helps them to make connections between different mathematical domains (Grover & Pea, 2013). In other words, integrating CT into ME can prepare students to solve more challenging mathematical problems, improve their ability to reason logically, and have a deeper knowledge of mathematical ideas when they are taught to think computationally (Cui & Ng, 2021; Wing, 2006).

In addition, the integration of CT into ME can lead to increased student engagement and motivation by providing opportunities for experiential learning, exploration, and creativity (Kalelioglu et al., 2016). CT-based activities, such as programming and coding, allow students to actively construct their understanding of mathematical concepts through hands-on experiences (Weintrop et al., 2016). This can lead to a deeper connection with the content and a greater sense of ownership over their learning, resulting in increased motivation, engagement and persistence in ME (Yadav et al., 2014).

Furthermore, incorporating CT into ME can better prepare students for future careers by developing skills that are highly valued in the modern workforce, such as critical thinking, collaboration, and adaptability (Voogt et al., 2015). As technology continues to play an increasingly significant role in various industries, the demand for individuals with strong CT skills is expected to grow (Bocconi et al., 2016). By integrating CT into ME, students can develop a strong foundation in these skills, which can be applied to various career paths, both within and beyond the field of mathematics (Pollock et al., 2019).

### 2.3.13 Challenges to integrating computational thinking into mathematics education

Since it is already challenging to promote CTE, integrating CT in ME poses additional challenges. The following summarizes the challenges from the perspectives of four key stakeholders: school administrators, teachers, parents, and students.

Firstly, from a school administrative perspective, the successful integration of CT into ME requires the development of a strategic plan, which includes addressing teacher preparedness, curriculum alignment, resource allocation, and assessment (Barr & Stephenson, 2011). Administrators play a vital role in providing educators with adequate professional development opportunities to build their skills and confidence in teaching CT (Israel et al., 2022). Additionally, administrators must ensure that curricula are designed to effectively incorporate CT concepts while maintaining the core mathematical content (Lye & Koh, 2014). Access to resources and technology is another area of concern for administrators, as they must allocate funds and resources to support CT integration, particularly in under-resourced schools (Kale et al., 2018).

Secondly, teachers face multiple challenges when integrating CT into ME, including a lack of background knowledge in computer science, limited experience with CT pedagogies, and the need to balance CT with existing curriculum demands (Yadav et al., 2016). To address these challenges, professional development programs should provide teachers with the necessary knowledge, skills, and pedagogical strategies for teaching CT (Sáez-López et al., 2016). Teachers also play a key role in designing and implementing CT-rich activities that align with both CT and ME standards (Weintrop et al., 2016). Assessment of CT skills and learning outcomes is a complex task for teachers due to the multidimensional nature of CT, requiring the development of valid and reliable assessment tools (Grover & Pea, 2013).

Thirdly, parents, as key stakeholders in their children's education, need to be aware of the importance of CT in preparing students for future careers and problem-solving skills (Cai & Wong, 2023; Ohland et al., 2019). They can support their children's learning by encouraging them to engage in CT activities outside of the classroom, such as coding clubs, online resources, or summer camps (Li & Yang, 2023). Furthermore, parents can advocate for the integration of CT into ME at their children's schools, ensuring that all students have access to CT learning opportunities. Parents can also help bridge the digital divide by providing access to technology and resources at home, as well as supporting low-resource solutions for integrating CT into ME (Bocconi et al., 2016).

Fourthly, students are the primary beneficiaries of CT integration in ME, as it enhances their learning experiences and prepares them for a rapidly evolving digital world (Lye & Koh, 2014). However, students face challenges in developing CT skills, such as overcoming misconceptions about computer science, maintaining motivation, and balancing CT learning with other academic demands (Curzon et al., 2014; Vaníček et al., 2022). Teachers can support students by designing engaging and meaningful CT activities that promote problem-solving, creativity, and collaboration (Brennan & Resnick, 2012). Students can also be encouraged to take ownership of their learning by participating in extracurricular activities related to CT, such as coding clubs or competitions (Tabesh, 2017).

### 2.3.14 Teacher professional development in integrating computational thinking into mathematics education

The importance of teacher preparation for integrating CT into ME cannot be overstated, as many teachers may not be conversant with CT principles (Li, 2021). Teachers must learn how to successfully incorporate CT into existing courses, necessitating the development of educational practices that promote student participation, teamwork, and critical thinking skills (Dong et al., 2019).

Supporting teachers in integrating CT into ME requires ongoing professional development (PD) opportunities that focus on both content knowledge and pedagogical strategies (Yadav et al., 2017). PD should emphasize the connections between CT and mathematical thinking, as well as provide teachers with practical strategies for curricular integration and classroom implementation (Bocconi et al., 2016). Additionally, PD should foster a community of practice, wherein teachers can collaborate, share ideas, and reflect on their experiences integrating CT into ME (NCTM Research Committee, 2018).

The use of CT in a professional development program for math teachers was examined in a research by Yadav et al. (2014). The goal of the research was to determine the difficulties and advantages of incorporating CT into mathematics instruction as well as the effects of professional development on teachers' pedagogical practices. The study's conclusions showed that a considerable change in pedagogy, from a teacher-centered to a student-centered approach, was necessary for the integration of CT into mathematics teaching. In CT, teacher professional development is required, and it must be integrated into mathematics instruction, according to the report. Teachers were taught CT principles and how to use them into ME throughout a series of seminars that made up the professional development program. Along with observations and comments from teachers in the classroom, the program provided chances for teacher cooperation and reflection. The results demonstrated that the professional development program was successful in encouraging modifications to teachers' pedagogical practices, notably in their use of technology and student-centered methods. The research emphasized how crucial teacher professional development is to encouraging the inclusion of CT in mathematics instruction.

### 2.3.15 Assessment for integrating computational thinking into mathematics education

To effectively assess the integration of CT in ME, the development of suitable assessment frameworks is paramount. Grover, Pea, and Cooper (2015) argue that these frameworks should reflect the multidimensional nature of CT, encompassing skills such as algorithmic thinking, problem decomposition, and debugging. Moreover, frameworks should align CT outcomes with ME standards, ensuring that the assessment of CT integration does not overshadow essential mathematical learning goals (Lye & Koh, 2014).

Recent research suggests that formative assessment approaches can be particularly beneficial for gauging the progress of CT integration in ME (Hadad et al., 2020; Koh et al., 2014). Formative assessments provide timely feedback to both students and educators, enabling the adjustment of instructional strategies according to learner needs (Hadad et al., 2020). Moreover, they can facilitate the development of metacognitive skills, as students reflect on their own CT processes and mathematical understanding (Hadad et al., 2020).

The development of reliable and valid assessment tools is another critical aspect of evaluating CT integration in ME. Weintrop et al. (2016) highlight the need for tools that measure both the procedural and conceptual aspects of CT, capturing the nuances of students' understanding and abilities. As a result, a combination of assessment methods is often recommended, including performance-based tasks, coding projects, and written tests (Denning & Tedre, 2019). Emerging assessment tools, such as automated coding assessments and intelligent tutoring systems, leverage technology to provide immediate feedback and personalized learning pathways for students (Alves et al., 2019). These tools can be particularly useful in assessing CT skills, such as debugging and algorithm development, while simultaneously promoting mathematical understanding.

## 2.4 Review of Recent Research Studies

In recent years, several evaluations of CT in education have been conducted. Grover and Pea's (2013) investigation into CT discourse in K-12 education was inspired by Wing's (2006) call for CTE. The review revealed a lack of studies on using CT to teach other subjects. To provide the most recent breakthroughs in empirical research on CTE in from kindergarten to secondary school, Lye and Koh (2014) studied 27 studied intervention research. Of these, nine studies involved K-12 students, but none addressed the relationship between CT and mathematics, nor were any conducted in a primary school setting.They concluded that visual programming languages were the predominant digital experiences in ME. In K-12 schools, three popular programming languages are taught. Only 9% of the studies in Zhang and Nouri's (2019) research, which focused on how K-9 children used Scratch to develop relevant skills, evaluated the integration of Scratch and mathematics. Few studies have investigated CT in relation to mathematics, and to the best of our knowledge, none have specifically examined it in basic mathematics. This is not to say that there are no mathematical applications for CT. For example, Hickmott et al. (2018) searched for peer-reviewed publications addressing CT in the K-12 educational context published between 2006 and 2016, focusing on research in the areas of computer science (CS) and ME. They sought evidence that these studies linked CT to mathematics learning and, if so, how. The authors found that a significant portion of the evaluated research used a coding language while instructing students CT. They also concluded that reports of students' math learning outcomes were scarce and that research explicitly demonstrating a connection between the acquisition of mathematical concepts and CT was rare. Barcelos et al. (2018) provided another literature review of articles released from 2008 to 2017 to identify research exploring how the relationship between mathematics and CT has been emphasized through didactic activities at different educational levels. They discovered that the didactic activities used in the studies they included covered a broad range of mathematical concepts and employed various computer technologies. Moreover, they posited that computational concepts and software tools held considerable potential for enhancing ME. This systematic review builds upon the reviews by Hickmott et al. (2018) and Barcelos et al. (2018) in two specific ways.

First, it continues where these two reviews left off, as the articles analyzed cover the years 2015 to 2021, even though the search period extended from 2000 to 2021. Second, it refines and expands upon their prior works by concentrating on the teaching and learning of CT in fundamental ME. As such, determining if and how basic mathematics can benefit from the integration of CT is crucial, especially considering the recent growth of CT in both secondary and elementary ME. The primary goal of this work aligns with, originates from, and is informed by the latest developments in the field.

To improve students' ability to solve problems and engage in critical thought, the incorporation of CT into mathematics instruction is becoming more and more common. A research was done by Resnick et al. (2009) to determine how "design-based learning" (DBL), a novel method of instructing science and engineering, affected the students' capacity for creativity and problem-solving. In the research, 150 students were split into two groups: a treatment group that got education using DBL and a control group that received instruction the conventional way. The students came from four different American schools. When compared to students who received standard education, the researchers discovered that students who got DBL instruction shown substantial increases in their ability to solve problems creatively. Incorporating CT into K–12 instruction may benefit kids' cognitive development, according to the research, and teaching CT to young pupils may be accomplished successfully using visual programming tools like Scratch. According to Resnick et al. (2009), the CT-based group had considerable increases in their problem-solving abilities, including their capacity to characterize issues, see patterns, and create algorithms. Additionally, using CT-based exercises in math classes helped students develop their analytical and critical thinking abilities. According to Resnick et al. (2009), students who participated in CT-based learning activities were better able to think critically about the issues they were tackling and come up with workable solutions.

The results of the research imply that incorporating CT into mathematics instruction may be a successful strategy to improve students' capacity for problem-solving and critical thought. Students get the chance to fully grasp mathematical ideas and apply them in practical settings via CT-based exercises. This method may prepare children for future jobs that need strong problem-solving and critical thinking abilities, such as those in the domains of STEAM (Resnick et al., 2009). In order to determine how teaching CT affects students' 21st-century abilities, Voogt et al. (2015) carried out a quasi-experimental research. 146 pupils from four different secondary schools in the Netherlands, ranging in age from 12 to 16, participated in the research. The 10-week CT program was given to the treatment group, but not to the control group. The conventional method group received instruction using traditional techniques, while the CT-based group received instruction utilizing CT-based activities. The research discovered that students who engaged in CT-based activities outperformed those who received standard mathematics instruction in logical reasoning and critical thinking tests. The researchers discovered that the CT program had a favorable effect on students' 21st-century abilities, such as teamwork, communication, and critical thinking. According to the study's findings (Voogt et al., 2015), teaching CT to secondary school students may be a useful strategy for encouraging the development of 21st-century abilities. Additionally, better learning results were obtained as a result of the use of CT in mathematics teaching. According to the study's findings (Voogt et al., 2015), students in the CT-based group showed a greater comprehension of mathematical topics, were able to apply their knowledge in practical settings, and shown improved problem-solving abilities. According to the study's results, including CT into mathematics instruction may help students become more adept at logical reasoning and critical thinking, as well as increase learning outcomes. Students may learn mathematical concepts and apply them in practical situations using CT-based activities, preparing them for professions in STEAM disciplines in the future (Voogt et al., 2015). To enhance student learning results and better prepare them for the future, it is crucial to think about incorporating CT into mathematics teaching.

CT integration into early childhood education has been linked to improved pupils' creativity and problem-solving abilities, according to research by Bers et al. (2014). A 14-week curriculum using the developmentally appropriate programming language ScratchJr was employed in the research, which included 65 kindergarten and first-grade pupils. Comparing students who took part in the program to a control group who did not get the intervention, the researchers discovered that these students significantly improved their ability to solve problems and think creatively. According to the research, using CT-based exercises increase students' interest in arithmetic and motivation. Due to the fact that the students perceived the CT-based activities to be more engaging and difficult than the standard mathematics curriculum, they were more motivated and interested in participating (Bers et al., 2014). In addition, using CT-based exercises helped students' teamwork abilities to grow. In order to complete projects and address difficulties, students had to collaborate, which improved their leadership, collaboration, and communication abilities (Bers et al., 2014). The research also showed that the usage of CT-based activities promoted the growth of students' creative thinking and problem-solving skills. Students had the chance to use mathematical ideas to assess issues, think critically, and come up with appropriate answers thanks to CT-based activities (Bers et al., 2014). According to the study's results, including CT into mathematics instruction may boost students' creativity, teamwork, and problem-solving abilities while also increasing their motivation and engagement. In order to better educate students for future professions in STEAM sectors, CT-based activities may provide them a learning experience that is more meaningful and relevant (Bers et al., 2014). To enhance students' learning results and encourage their future success, it is crucial to take into account the integration of CT into mathematical teaching.

## 2.5 Conceptual Framework

The conceptual foundation of this research is the fusion of mathematical and CTE. Constructivism, the zone of proximal development (ZPD), and the TPACK framework are just a few of the theoretical frameworks and ideas that serve as the foundation for this integration. Constructivism is a philosophy of learning that places an emphasis on the learner actively creating knowledge (Jonassen & Rohrer-Murphy, 1999). Constructivism contends that students should actively participate in problem-solving activities that call for the use of CT abilities and mathematical ideas in the context of CTE and ME. This strategy encourages greater comprehension and memory of the material as well as the development of transferrable abilities that may be used in practical situations.

Constructivism, as described by Jonassen and Rohrer-Murphy (1999), sees learning as an active process that entails the creation of knowledge via meaningful experiences. The way that learners interact with their learning environment and the world around them influences how they perceive it. In the context of CT and ME, where students may actively participate in CT-based activities to hone their problem-solving and critical thinking abilities, this strategy is especially pertinent. Researchers looked at the effects of constructivist methods on learning outcomes in ME in a study by Omotayo and Adeleke (2017). In comparison to pupils who got conventional training, the research indicated that students who received constructivist instruction significantly improved their problem-solving skills. According to the research, constructivist methods encourage the development of transferrable problem-solving abilities as well as a better comprehension of mathematical ideas.

In addition, a research by Ma et al. (2021) looked at how students' problem-solving skills and CT skills were affected by a constructivist approach to CT instruction. In comparison to students who received conventional training, the research indicated that pupils who received constructivist instruction significantly improved their problem-solving and CT skills. According to the research, a constructivist approach to CTE may help students gain transferrable abilities that they can use in real-world situations. Constructivism is a philosophy of learning that places an emphasis on the student actively creating knowledge. Constructivist methods may help students grasp concepts better, retain information, and acquire transferable abilities in the context of CT and ME. Constructivist methods may help students develop their problem-solving and critical thinking abilities while also preparing them for employment in STEAM sectors via the merger of CT and mathematics instruction.

Because it highlights the need of scaffolding and assistance in fostering learning and skill development, Vygotsky's ZPD is a useful idea for CT and mathematical education (Taylor, 1993). According to Vygotsky (1978), if a student receives direction and help from a more experienced person, they may execute activities that are above their present level of comprehension and expertise. This indicates that learners should be given activities that are slightly beyond their present level of comprehension in the context of CT and mathematical instruction, but with the proper scaffolding and assistance. Studies have shown the ZPD approach's efficacy in CT and math instruction (Basawapatna et al., 2013; Kotsopoulos et al., 2017; Lavigne et al, 2020). For instance, a research conducted by Basu et al. (2017) examined the use of a CT-based online game with scaffolding to encourage the growth of students' problem-solving abilities. According to the findings, the game—which was made to fit inside the students' ZPD—was successful in fostering their capacity for problem-solving. Catlin and Woollard (2014) also looked at the effects of a CT-based educational program that included ZPD principles on students' CT proficiency and mathematics success. As part of the curriculum, pairs of pupils solved mathematics problems based on CT while receiving instruction and assistance from professors. The findings highlighted the significance of ZPD principles in CT and ME by demonstrating the program's efficacy in fostering students' mathematical success and CT abilities.

As it highlights the need of scaffolding and assistance in fostering learning and skill development, Vygotsky's notion of the ZPD is a crucial tool in CT and mathematical education. The ZPD technique has been shown to be beneficial in raising kids' achievement in math, CT, and problem-solving abilities. The TPACK framework emphasizes the junction of technical, pedagogical, and subject knowledge to provide a comprehensive approach to the integration of CT and mathematical education. According to Mishra and Koehler (2006), all three knowledge areas must be combined in order for CT to be effectively integrated into mathematics instruction. To successfully teach CT skills in the context of mathematics, educators must first have a solid grasp of mathematical principles and subject-matter expertise (Mishra & Koehler, 2006). Secondly, in order to successfully incorporate CT into their teaching practices, educators must possess pedagogical knowledge and abilities. This includes the capacity to create CT-based activities that promote student-centered learning, provide the proper scaffolding and support, and line up with learning goals (Mishra & Koehler, 2006).

Finally, teachers must be adept at using the digital tools and resources that may help them teach CT and mathematics. This involves using coding languages, software, and internet resources that may aid in the development of CT abilities and promote the study of mathematics (Mishra & Koehler, 2006). By placing a strong emphasis on the confluence of technical, pedagogical, and subject knowledge, the TPACK framework offers a complete approach to the integration of CT and mathematical education (Kale et al., 2018; Kong & Lai, 2021). This strategy may assist teachers in successfully integrating CT abilities into mathematics instruction and preparing students for occupations that call for strong problem-solving and critical thinking abilities, such as those in STEAM areas (Mishra & Koehler, 2006). In order to engage students in deeper learning and the development of transferable skills, PBL, a pedagogical method, stresses the use of actual, real-world issues (Savery &

Duffy, 1995). PBL may be used in the context of CT and math education to effectively and meaningfully combine CT abilities and mathematical ideas. PBL may foster a better grasp of these subjects as well as the development of transferable skills by involving students in projects that call for the application of CT and mathematical principles to solve real-world situations (Saad & Zainudin, 2022). The development of CT abilities including issue decomposition, abstraction, and algorithm design may be facilitated by PBL, in accordance with Saad and Zainudin (2022). PBL may also assist students in making links between mathematical ideas and practical applications, which will aid in their grasp of both subjects. Moreover, PBL may support the development of transferable abilities like critical thinking, teamwork, and communication, which are crucial for success in both academic and real-world situations (Savery & Duffy, 1995). To encourage deeper learning, the development of transferable skills, and the meaningful and relevant integration of CT and mathematical ideas, PBL integration into CT and ME may be an effective strategy.

Constructivism, the ZPD, the TPACK framework, and PBL are all included into the study's conceptual framework. In order to improve students' CT abilities and mathematical understanding, effective teaching methodologies and digital resources are developed using a mix of theoretical frameworks that serves as a foundation for combining CT and ME. Through problem-solving activities that call for the use of CT abilities and mathematical ideas, learners actively create knowledge and gain transferable skills while using a constructivist approach. The ZPD places a strong emphasis on pushing students just a little bit beyond their comfort zone while still offering the necessary scaffolding and assistance. The TPACK framework emphasizes the need for teachers to have knowledge of pedagogy, CT, mathematics, and effective use of digital resources. Last but not least, PBL encourages the utilization of real-world issues to involve students and foster the development of transferable abilities.

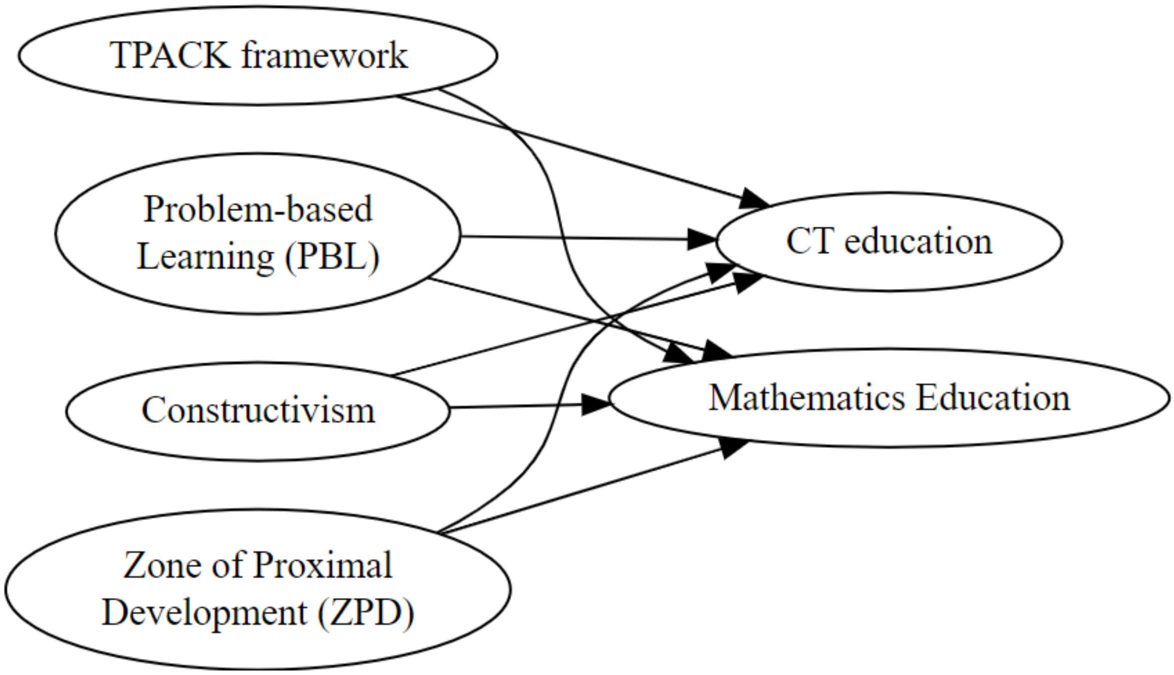



Figure 2. Conceptual Framework: Effective Approaches to Integrating CT into ME

## 2.6 Gaps in the Existing Literature

The existing literature on the integration of CT in ME has provided valuable insights into the potential benefits of this approach for students' learning outcomes and motivation. However, there remain several gaps in the literature that warrant further investigation. These gaps have led to the formulation of three research questions, which are outlined below.

Research Question 1: [RELATIONSHIP] What is the relationship between CTE and ME? What are the roles of CT Concepts (Coding Skills), CT Practices (Problem-solving Skills), and CT Perspectives (Identity and Motivation) in ME from educators' and students' perspectives?

Firstly, while previous studies have explored the general relationship between CT and ME, there is limited understanding of the specific roles that CT concepts, practices, and perspectives play in enhancing students' mathematics learning. A more nuanced examination of these aspects could provide valuable information for educators seeking to optimize the integration of CT in their mathematics instruction. Furthermore, the existing literature primarily focuses on the perspectives of researchers, with few studies exploring the experiences and viewpoints of educators and students. Understanding the perspectives of these stakeholders is crucial for the successful implementation of CT in ME.

Research Question 2: [ACADEMIC PERFORMANCE] How are students benefiting from integrating CTE into ME? What are the effects of the integration implementation on students' performance in mathematics?

Secondly, although some studies have reported positive effects of CT integration on students' mathematics performance, the literature lacks a comprehensive understanding of the specific benefits that students gain from this approach. Additionally, there is limited research on the factors that contribute to successful integration and the potential challenges that educators face when implementing CT in their classrooms. A deeper investigation into these areas could provide essential guidance for educators and policymakers seeking to promote the effective integration of CT in ME.

Research Question 3: [LEARNING MOTIVATION] Are students motivated to learn mathematics through coding activities in CTE?

Thirdly, motivation is a critical factor in students' learning and academic success. Although some studies suggest that CT integration can enhance students' motivation to learn mathematics, there is limited research specifically examining the impact of coding activities on students' motivation. A focused investigation into this area could provide valuable insights into the potential of coding activities to engage and motivate students, as well as inform the development of effective strategies for incorporating coding activities into mathematics instruction.

In summary, addressing these gaps in the existing literature is crucial for advancing our understanding of the benefits and challenges associated with integrating CT in ME. By exploring the relationships between CT concepts, practices, and perspectives, the effects of CT integration on students' academic performance, and the impact of coding activities on students' motivation to learn mathematics, researchers can make a significant contribution to the development of effective strategies for enhancing students' learning experiences and outcomes in ME.

# 3. METHODOLOGY

## 3.1 Research Design

As it offers a more thorough knowledge of challenging research topics, the employment of a mixed-methods approach has grown in popularity over the last few years, especially in social and educational research (Johnson & Onwuegbuzie, 2004). To gather and evaluate both quantitative and qualitative data for this research, a mixed-methods technique was used. The necessity for a thorough grasp of the study topic and the need to triangulate the results served as the justification for this choice of strategy.

A survey and test were given to senior primary school pupils who were taking mathematics and CT classes in the first phase, which included the collection of quantitative data. The purpose of the survey was to gather data on the students' attitudes toward mathematics and CT, and their comprehension of the advantages of integrating these topics. In order to generate a representative sample, the survey was given to all of the grade 6 pupils at the chosen school. To make sure the survey was genuine and trustworthy, it was carefully crafted. The study topics served as the basis for the development of the questions, which underwent pretesting to verify that they were intelligible and clear. In order to verify that the results were similar, the survey was given to the experimental group after receiving the intervention. Statistics were used to examine the survey data in order to look for patterns and trends. Tests were created to evaluate the students' CT and mathematics capabilities in addition to the survey. The assessments were created to evaluate the students' capacity for mathematical problem-solving and their comprehension of CT ideas. To make sure the tests were trustworthy and legitimate, substantial planning went into their design. The study topics served as the basis for the development of the questions, which underwent pretesting to verify that they were intelligible and clear. To guarantee that the results were comparable, the examinations were given in a same way throughout all students. In order to find patterns and trends, the test-related data was evaluated statistically. The use of surveys and tests in this study produced quantitative data that was statistically analyzed in order to make judgments about the students' current level of education in mathematics and CT, their attitudes toward these subjects, and their comprehension of how the integration of these subjects can be advantageous. The findings from the survey and tests provide a strong basis for making judgments and suggestions for further study or practice.

The second part of the study's qualitative data collection was teachers interviews and classroom observations. Over the CT activities as the intervention of many weeks, classroom observations were done to see how teachers were incorporating CTE into the teaching of mathematics. The tactics used by the teachers, their efficacy, and any difficulties experienced during the observations were all noted. The observations were carried out in a way that caused the least amount of interruption to the learning environment. Without interfering with the lessons being taught, the observer would quietly make notes on the methods teachers used and how well they worked. To guarantee the accuracy of the data gathered, thorough and in-depth notes were made. To learn more about the teachers' perspectives on the incorporation of CTE into ME, interviews were arranged in addition to classroom observations. The in-person interviews were audio recorded for subsequent transcription and were done in-person. The interview questions were open-ended to encourage thorough and significant replies. Because the interviews took place in a private setting, the teachers could express themselves without worrying about being judged or punished. To find patterns and themes, the information gathered from classroom observations and interviews was examined using qualitative techniques. It was possible to get a greater knowledge of how teachers were integrating CTE into mathematics instruction thanks to the observations and interviews, which offered a rich supply of data. The utilization of qualitative data in this research allowed for a thorough knowledge of the methods teachers used to include CTE into mathematics instruction, the difficulties they faced, and their opinions on the topic. A thorough knowledge of the study topic was made possible by the observations and interviews, which offered insightful observations in addition to the quantitative information gathered by surveys and tests.

The triangulation of the results was made possible by the employment of both quantitative and qualitative data gathering techniques, which is a significant advantage of the mixed-methods approach (Turner et al., 2017). Triangulation is the process of using data from many sources to confirm and verify the results (Thurmond, 2001). The results of this study's analysis of the quantitative and qualitative data were compared to see whether they were similar or different. It increased trust in the validity of the results if the results were consistent. If the results were inconsistent, it indicated that the study topic was complicated and needed further research. The themes that arose from the data but were not foreseen by the research questions or the literature were identified using the inductive technique. This technique allows for a thorough analysis of the data and a thorough comprehension of the study's problem (Bloor, 1978).

Furthermore, to investigate the content and context of CT practices in mathematics teaching and learning, content analysis will be utilized, encompassing written and visual sources, such as articles, events, projects, symposiums, blogs, documentaries, and videos. The aim is to gain a deeper understanding of the approaches employed to incorporate CT into the ME curriculum in contemporary schools. Content analysis has been defined as "a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" (Krippendorff, 2018, p.24). Texts can encompass a wide array of informational sources, including images, sounds, videos, various forms of artwork, social media posts, and statistics (Flick, 2009). Based on the goals of the data collection project and the content of the selected online resources, categories will be organized to conduct content analysis. Once coded, the themes and ideas revealed by the content analysis will be explained, along with their occurrences and relationships.

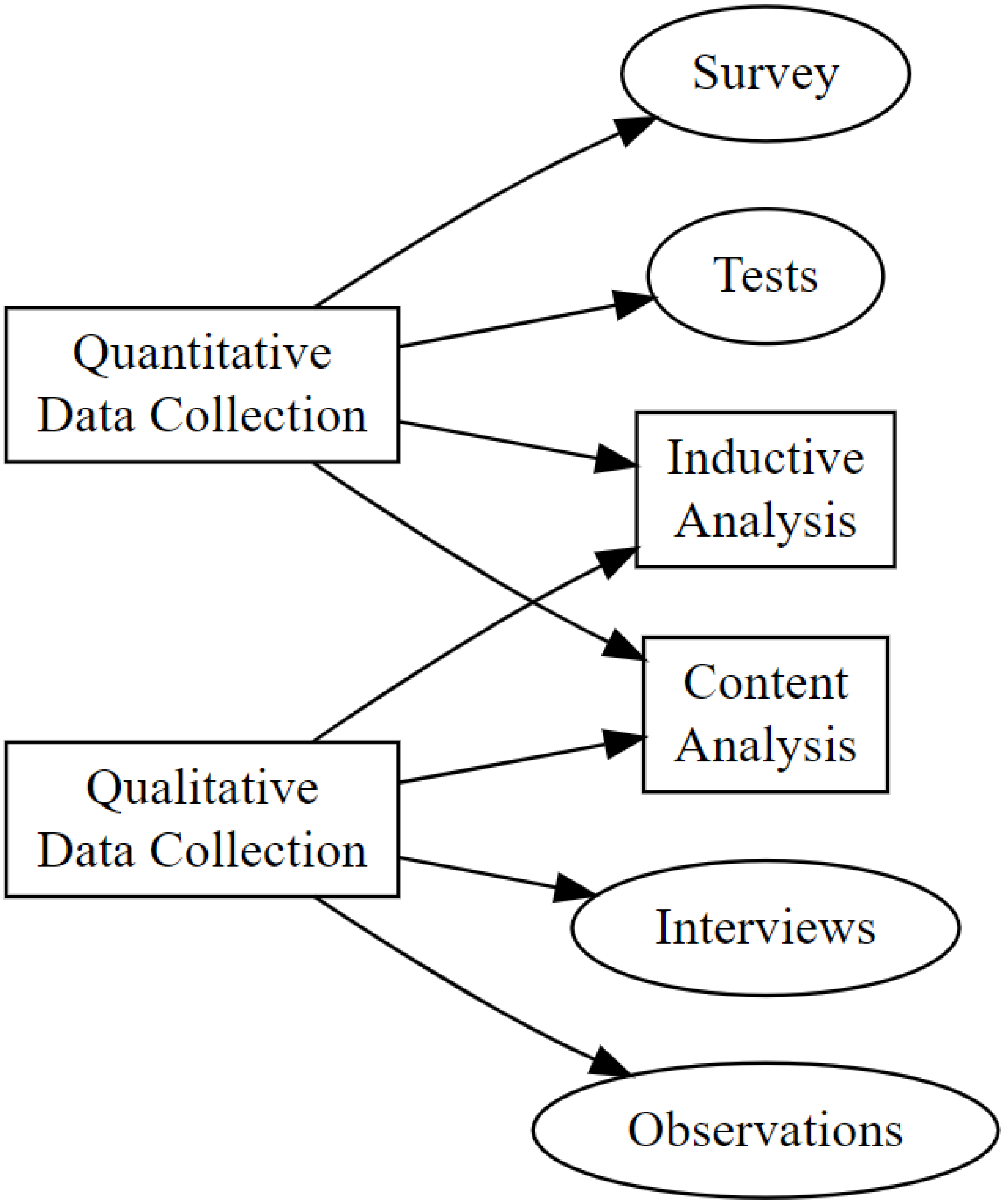



Figure 3. Mixed Methods Research Design

## 3.2 Intervention - CT curriculum

The researcher has designed a curriculum to examine the significance of integrating CTE into ME in senior primary school. The curriculum is structured around the VinciBot

Coding Robot Set, a tool that supports a wide range of applications in the STEAM education industry. By leveraging the capabilities of VinciBot and its block programming language, the curriculum aims to provide an effective intervention for the research study that combines CT and ME.

The curriculum consists of nine double lessons, with each lesson addressing specific learning objectives in both CT and ME. The lessons are designed to progressively build on the students' knowledge and skills in these areas, ensuring that they develop a strong foundation in both CT and mathematical concepts, as shown below.

**Lesson 1: Introduction to VinciBot and Basic Programming**

Computational Thinking Objectives:

1. Understand the basics of the VinciBot Coding Robot Set.
2. Learn how to use the block programming language.

Mathematics Education Objectives:

1. Understand the concept of sequencing and ordering.
2. Apply sequencing to simple arithmetic operations (addition, subtraction).

Learning Content:

- Introduction to the VinciBot Coding Robot Set and its components.
- Introduction to block programming and basic commands.
- Creating a simple program to perform arithmetic operations using sequencing.

**Lesson 2: Geometry Basics and Robot Movement**

Computational Thinking Objectives:

1. Learn how to control VinciBot's movements using programming.
2. Understand how to use loops and conditional statements in block programming.

Mathematics Education Objectives:

1. Understand the concepts of angles and basic geometric shapes.
2. Measure and create angles using VinciBot.

Learning Content:

- Review of angles and geometric shapes.
- Programming VinciBot to move in specific directions and create shapes.
- Using loops and conditional statements to draw shapes with VinciBot.

**Lesson 3: Distance and Speed**

Computational Thinking Objectives:

1. Learn how to use variables in block programming.
2. Understand the relationship between distance, speed, and time.

Mathematics Education Objectives:

1. Apply the concepts of distance, speed, and time to real-life situations.
2. Solve problems involving distance, speed, and time.

Learning Content:

- Introduction to variables in block programming.
- Programming VinciBot to move at different speeds and distances.
- Solving distance, speed, and time problems using the programming skills learned.

**Lesson 4: Fractions and Robot Movements**

Computational Thinking Objectives:

1. Learn how to use arithmetic operations with fractions in block programming.
2. Understand how to apply fractions to control VinciBot's movements.

Mathematics Education Objectives:

1. Understand and apply the concepts of fractions.
2. Perform arithmetic operations with fractions.

Learning Content:

- Review of fractions and arithmetic operations with fractions.
- Programming VinciBot to perform movements using fractions.
- Creating programs that involve fractions and arithmetic operations.

**Lesson 5: Coordinate System and Robot Positioning**

Computational Thinking Objectives:

1. Learn how to use the coordinate system in block programming.
2. Understand how to program VinciBot to move to specific positions using coordinates.

Mathematics Education Objectives:

1. Understand the concepts of coordinate systems and graphing.
2. Plot points and shapes on a coordinate plane.

Learning Content:

- Introduction to coordinate systems and graphing.
- Programming VinciBot to move to specific positions using coordinates.
- Plotting points and shapes using VinciBot and the coordinate system.

**Lesson 6: Logical Operations and Robot Decision-Making**

Computational Thinking Objectives:

1. Learn how to use logical operations in block programming.
2. Understand how to program VinciBot to make decisions based on conditions.

Mathematics Education Objectives:

1. Understand the concepts of logical operations and their applications in mathematics.
2. Solve problems using logical operations.

Learning Content:

- Introduction to logical operations and their applications in mathematics.
- Programming VinciBot to make decisions based on conditions using logical operations.
- Solving problems using logical operations with block programming.

**Lesson 7: Data Representation and Graphing**

Computational Thinking Objectives:

1. Learn how to represent data using lists and arrays in block programming.
2. Understand how to create graphs using VinciBot and programming.

Mathematics Education Objectives:

1. Understand the concepts of data representation and graphing.
2. Analyze and interpret data from graphs.

Learning Content:

- Introduction to data representation and graphing in mathematics.
- Programming VinciBot to create graphs using lists and arrays.

- Analyzing and interpreting data from graphs created by VinciBot.

**Lesson 8: Probability and Randomness**

Computational Thinking Objectives:

1. Learn how to use random functions in block programming.
2. Understand how to program VinciBot to perform tasks based on probability.

Mathematics Education Objectives:

1. Understand the concepts of probability and randomness.
2. Calculate probability and make predictions based on probability.

Learning Content:

- Introduction to probability and randomness in mathematics.
- Programming VinciBot to perform tasks based on probability using random functions.
- Calculating probability and making predictions using VinciBot and block programming.

**Lesson 9: Project-Based Learning and Showcase**

Computational Thinking Objectives:

1. Apply the skills learned in previous lessons to create a project.
2. Showcase the project to demonstrate understanding of computational thinking and mathematics education concepts.

Mathematics Education Objectives:

1. Demonstrate the application of mathematical concepts through a project.
2. Present and explain the project to peers and/or instructors.

Learning Content:

- Students will work individually or in small groups to create a project using the skills learned in previous lessons.
- The project should integrate computational thinking and mathematics education concepts, such as solving a real-life problem, creating a game, or designing an interactive exhibit.
- Students will showcase their projects and explain their work, highlighting the mathematical concepts and programming techniques used.

The researcher designed an intervention in the form of a curriculum, which aims to investigate the significance of integrating CTE into ME in senior primary school. This well-structured curriculum revolves around the VinciBot Coding Robot Set, a versatile tool designed to support a broad range of applications in the STEAM education industry. By utilizing the capabilities of VinciBot and its block programming language, the curriculum offers an effective intervention approach that combines CT and ME.

The curriculum is designed with a clear pedagogical progression in mind, starting with basic programming concepts and gradually moving towards more complex mathematical and computational thinking topics.

The first lesson introduces students to the VinciBot Coding Robot Set and its components, as well as the block programming language. This lesson focuses on the fundamentals of programming and sequencing, with students learning how to perform simple arithmetic operations using the block programming language. The lesson's objectives are aligned with the overarching aim of the research study by providing a solid foundation in both CT and ME.

In subsequent lessons, the curriculum delves deeper into more advanced concepts in both CT and ME. For example, in Lesson 2, students learn about geometry, robot movement, and the use of loops and conditional statements in block programming. This lesson builds on the foundational concepts introduced in Lesson 1 and demonstrates how CT and ME can be effectively integrated using the VinciBot coding robot.

As the curriculum progresses, students learn about various mathematical concepts such as distance, speed, time, fractions, coordinate systems, logical operations, data representation, graphing, probability, and randomness. In each lesson, the researcher integrates these mathematical concepts with computational thinking skills, such as using variables, arithmetic operations, and logical operations in block programming. This integration of CT and ME is central to the overall purpose of the research study, as it allows students to develop a comprehensive understanding of both areas simultaneously.

The curriculum culminates in a project-based learning and showcase lesson, where students are tasked with applying the skills and knowledge they have acquired throughout the course to create a project that demonstrates their understanding of CT and ME concepts. This final lesson serves as an opportunity for students to synthesize the knowledge gained in previous lessons and showcase their ability to effectively integrate CT and ME in a real-life application.

In short, the researcher's intervention design, which consists of a curriculum centered around the VinciBot Coding Robot Set, is well-aligned with the overall purpose of the research study. This curriculum is carefully structured to integrate CT and ME concepts, enabling students to develop a strong foundation in both areas. By progressing from basic programming and mathematical concepts to more advanced topics, the curriculum allows students to build their skills and knowledge incrementally. Ultimately, the curriculum's project-based learning and showcase lesson serves as a capstone experience, allowing students to demonstrate their understanding of the significance of integrating CTE into ME in senior primary school.

## 3.3 Participants of the Study

The researcher has chosen to conduct the study in a specific primary school for several reasons, which render it an ideal setting to investigate the significance of integrating CTE into ME in senior primary school. A key factor influencing the selection of this school is its existing commitment to teaching Computational Thinking Education. The school has dedicated independent lesson time specifically for the purpose of teaching CTE, which provides a strong foundation for implementing the researcher's intervention. This dedicated lesson time ensures that the curriculum designed by the researcher can be seamlessly integrated into the existing school schedule, allowing for a more effective and comprehensive evaluation of the intervention's impact.

Another reason for selecting the specific primary school as the site for the research study is the researcher's position within the school as the head of STEAM education. As a result of this role, the researcher possesses in-depth knowledge of the school's educational practices, curriculum, and the needs of its students. This familiarity allows the researcher to tailor the intervention to the specific context of the school, ensuring that it is both relevant and engaging for the students. Additionally, the researcher's position within the school grants them access to necessary resources and support from the school administration, which is crucial for the successful implementation and evaluation of the intervention.

Furthermore, the school's commitment to STEAM education, encompassing Science, Technology, Engineering, Arts, and Mathematics, provides a conducive environment for the integration of CTE into ME. The school's emphasis on STEAM education implies that students and teachers are already familiar with interdisciplinary learning, which is essential for the effective integration of CTE and ME. The school's established culture of STEAM education also suggests that students are likely to be more receptive to the introduction of the researcher's intervention, as they are accustomed to learning in an integrated and interdisciplinary manner.

The selection of the school as the research site also facilitates the collection of reliable and valid data for the study. Given the researcher's position within the school and their familiarity with the educational practices, they are well-equipped to develop appropriate data collection methods and instruments that are contextually relevant. Moreover, the researcher's presence in the school enables them to closely monitor the implementation of the intervention, addressing any challenges that may arise and making necessary adjustments as needed to ensure its success.

In short, the selected school is an ideal setting for the researcher's study due to its existing commitment to CTE and STEAM education, the dedicated lesson time for CTE, the researcher's position as the head of STEAM education, and the conducive environment for the integration of CTE into ME. The selection of this school ensures that the researcher's intervention can be effectively implemented and evaluated, allowing for a comprehensive assessment of the significance of integrating CTE into ME in senior primary school.

Participants in this research included a principal, four STEAM curriculum coordinators, and one hundred and seven pupils from grade six of senior primary school. This study's participants were gathered through a variety of techniques. Email invitations were sent to the principal, curriculum coordinators inviting them to take part in the research and provide detailed information about the research. The parents were contacted via the schools that their kids attended, and they were requested to provide permission for their kids to participate. Through their teachers, the pupils were enlisted, and they received information about the research. The sample size was sufficient to guarantee statistical validity and included a wide variety of interested parties with various backgrounds and viewpoints on ME and CT. To guarantee a thorough knowledge of the effects of integrating CTE into mathematics instruction, a number of data gathering techniques were utilized. Principal, teachers and students were surveyed on how they felt about the integration, and exams were given to the children to gauge their grasp of mathematical ideas. In addition to conducting interviews with principal, teachers, and students to better understand their perspectives and experiences, classroom observations were done to see how teachers incorporated CT into their teaching and how students react in the lessons.

The school's participation in the study required the principal's approval, and the principal also assisted the teachers in implementing the integration by offering advice and assistance. To get opinions on how integration has affected the school and children, the principal was also questioned. By offering direction and assistance to their teachers as they implemented the integration, the STEAM curriculum coordinators contributed to the research. Additionally, they were spoken with to get their opinions on how the integration has affected the curriculum and student development. The coordinators also contributed to the research by offering advice and assistance to the teachers in their respective Key Learning Areas. Their comments on how the integration affected students were also sought out throughout the interviews. As they were in charge of integrating CT into ME, the STEAM curriculum coordinators as the teachers, were the study's main subjects. In order to gauge the integration's success, surveys were given to them on how they felt about the integration. They were also watched while they learned. For a greater understanding of their viewpoints and experiences, they were also interviewed. The integration mostly benefited the student participants, who underwent tests to gauge how well they understood various mathematical ideas. In order to gauge the integration's efficacy, they were also questioned about how they felt about it and observed it while they were in class.

In short, to achieve a complete knowledge of the effects of incorporating CTE into mathematics instruction, this research included a varied variety of participants, including students, teachers, curriculum coordinators, and principal. To gather information from the participants, the research used a mixed-methods approach that included questionnaires, tests, in-class observations, and interviews. Understanding how the integration has affected teaching and learning in ME has been made possible thanks to the participation of the many stakeholders. The study's subsequent phases will include data analysis and reporting so that future instructional strategies may be informed by the findings.

## 3.4 Data Collection Procedures - First Phase

### **3.4.1.** Systematic literature review & document analysis

The first phase of data collection of this study included conducting a systematic literature review and document analysis to gather relevant information and insights from existing research and educational documents. This process aimed to provide a comprehensive understanding of the significance of integrating CTE into ME in senior primary schools. To conduct the systematic literature review, a rigorous search strategy was implemented. The search terms used included "computational thinking education," "mathematics education," "senior primary schools," and related variations. The search was limited to articles published in English within the last 10 years to ensure the inclusion of recent and relevant literature.

The inclusion criteria for the literature review involved selecting studies that focused on integrating CTE in ME within the context of senior primary schools. Studies that explored the impact of such integration on student learning outcomes and the development of CT skills were prioritized. Additionally, only peer-reviewed journal articles and conference papers were considered to ensure the inclusion of high-quality research. Following the identification of relevant articles, a systematic screening process was undertaken. The titles and abstracts of the articles were reviewed to determine their alignment with the research objectives and inclusion criteria. Articles that did not meet the criteria or were deemed irrelevant were excluded. The remaining articles underwent a full-text review to assess their suitability for inclusion in the literature review.

During the data extraction process, key information and findings from the selected articles were systematically recorded. This included the research objectives, methodology, sample size, data collection methods, and the relationship between CT and ME. The data extraction process allowed for the identification of common themes, trends, and patterns across the literature. In addition to the systematic literature review, a document analysis was conducted to explore relevant educational documents, such as curriculum frameworks, policy documents, and educational guidelines. These documents provided valuable insights into the official recommendations and guidelines regarding integrating CTE into ME in senior primary schools.

The document analysis involved carefully examining the content of these documents to identify key themes and recommendations related to the integration of CT and ME. This process focused on understanding the current educational landscape, the goals and objectives set by educational authorities, and any existing frameworks or guidelines that promote the integration of CT concepts into ME curricula.

Tabel 1. Computational Thinking Curriculum Framework

| Publication Year | Document Title | Publisher | City / Country |
|---|---|---|---|
| 2020 | Computational Thinking – Coding Education: Supplement to the Primary Curriculum | The Education Bureau | HKSAR |
| 2017 | A Curriculum Framework for Hong Kong Students | CoolThink@JC | HKSAR |
| 2023 | Developing computational thinking and making as a national capability in Singapore | Code@SG | SG |
| 2021 | Computational Thinking for an Inclusive World: A Resource for Educators to Learn and Lead | Digital Promise | US |
| 2020 | Computational thinking framework | Raspberry Pi Foundation | UK |
| 2018 | Computational Thinking Framework | Let's Talk Science | CA |

Table 2. Mathematics Curriculum Framework

| Publication Year | Document Title | Publisher | City / Country |
|---|---|---|---|
| 2017 | Mathematics Education Key Learning Area Curriculum Guide | The Education Bureau | HKSAR |
| 2021 | Mathematics Syllabus (Primary One to Six) | Ministry of Education | SG |
| 2021 | National curriculum in England: mathematics programmes of study | Department for Education | UK |
| 2020 | The Ontario Curriculum Grade 1 - 8 | Government of Ontario | CA |

### 3.4.2. Students' term 2 test score in CT and ME

The researcher, in order to assess the relationship between students' performance in CT and ME in senior primary school, collected data on students' term 2 test scores in both CT and ME. This data will provide valuable insights into the academic performance of students as a result of the integration between CT and ME.

To collect the test score data, the researcher first obtains permission from the school administration. Once approval has been granted, the researcher gathers the existing term 2 CT test scores and ME test scores for the participating grade 6 students. These scores will serve as a crucial component of the data collection process.

In order to ensure the accuracy and reliability of the collected test scores, the researcher carefully reviews the test score records and verifies the data with the respective teachers and school administrators. Any discrepancies identified during this process are resolved before proceeding with the data analysis.

With the test score data collected, the researcher proceeds to analyze the relationship between students' performance in CT and ME. This includes comparing the students' test scores in both subjects, identifying any patterns or trends, and assessing the extent to which integrating CTE into ME has impacted students' academic performance.

## 3.5 Data Collection Procedures - Second Phase

### 3.5.1. Students' term 3 test score in CT and ME

After implementing the intervention that integrates CTE into ME in senior primary school, the researcher proceeds to collect data on students' term 3 test scores in both CT and ME. This data will be vital for evaluating the impact of the intervention on students' academic performance.

To collect the term 3 test score data, the researcher first ensures that the necessary permissions are in place from the school administration and the teachers involved in the study. Once granted, the researcher works closely with the teachers to obtain the students' term 3 test scores in the ME test.

The researcher pays close attention to the accuracy and reliability of the collected test scores. This involves verifying the data with the teachers and school administrators, and addressing any discrepancies found during this process.

Once the term 3 test score data has been collected, the researcher proceeds to analyze the data, comparing it to the term 2 test scores to identify any significant changes in students' academic performance. This analysis will involve assessing the relationship between students' performance in CT and ME, conducting descriptive statistics and hypothesis testing of inferential statistics.

### 3.5.2. Survey

The surveys conducted in this research were designed to collect valuable data on integrating CTE into ME in senior primary school. The design and development of the surveys considered the research objectives and aimed to gather insights from various stakeholders. This section discusses the design and development of the surveys, the target population, the sampling method, and the survey administration process. The target population for the surveys consisted of the pupils from grade six of senior primary school who received integrating CT into their math lessons as the intervention. The selection of participants aimed to capture insights involved in the implementation and reception of CTE in mathematics.

The surveys were designed to capture the quantitative data. The quantitative section consisted of close-ended questions, utilizing a Likert scale to measure participants' perceptions, attitudes, and experiences. The Likert scale allowed participants to rate their agreement or disagreement with specific statements related to integrating CTE into mathematics. Using a structured format enabled easy quantification and analysis of the responses.

The survey administration process involved distributing the surveys to the participants through various methods based on their preferences and availability. The surveys were administered in person, through online platforms during class time, to ensure all students responded. Clear instructions were provided to ensure that participants understood the purpose of the surveys and the specific instructions for completing them. Participants were given an adequate amount of time to complete the surveys, and reminders were sent to maximize response rates. The data collection period was carefully planned to accommodate participants' schedules and ensure a sufficient number of responses for meaningful analysis. To ensure confidentiality and anonymity, strict measures were implemented. Participants were assured that their responses would be kept confidential and used solely for research purposes. The surveys were coded to ensure that individual responses could not be linked back to specific participants, safeguarding their privacy. The surveys were designed, developed, and administered to gather comprehensive and reliable data on the integration of CTE into ME in senior primary school. The surveys were carefully tailored to capture both quantitative insights from the experimental group. The survey administration process took into account participants' preferences and privacy concerns while ensuring a representative sample.

The researcher in this study has strategically opted to appoint a teaching assistant (TA) to administer the survey with students in the class. This decision was made to ensure the objectivity and reliability of the students' responses. Several factors influenced this choice, one significant reason behind appointing a TA to conduct the survey is to reduce response bias. Students might feel pressured to provide the answers they believe the researcher wants or expects to hear if the researcher were to administer the survey themselves. By having a TA oversee the survey, the likelihood of response bias is minimized, allowing for more honest and genuine responses from the students. Another important aspect of using a TA in the survey process is maintaining the anonymity and confidentiality of the students' responses. Since the TA is not directly involved in the researcher's study, students may feel more comfortable sharing their true opinions, as they are less likely to fear potential repercussions or judgment from the researcher.

The presence of a TA during the survey process can also help foster familiarity and rapport with the students. If the TA is someone familiar to the students, such as an instructor or a fellow classmate, this familiarity can help build rapport between the TA and the students. In turn, this rapport can encourage students to be more forthcoming with their answers, providing more accurate and reliable data for the researcher. Involving a TA in the data collection process can also assist the researcher in reducing their own potential biases and preconceived notions about the study's outcomes. This can help ensure that the study's findings are more accurate and reliable, as they are less likely to be influenced by the researcher's own beliefs.

Therefore, these surveys served as a valuable resource for analyzing the perceptions, attitudes, and experiences regarding the integration of CTE, providing a solid foundation for further analysis in this research project.

### 3.5.3. Lesson observation

This study's second phase of data collection also focused on conducting observations to gather detailed information about integrating CTE into ME in senior primary schools. The purpose of these observations was to gain a comprehensive understanding of the dynamics within the classrooms and the instructional practices related to CT. An observational protocol was developed to ensure a systematic and consistent approach to data collection. This protocol included specific categories and indicators that guided the observations and captured relevant information. The categories encompassed various aspects, such as the strategies employed by teachers, student engagement in the lesson.

Data collection tools such as checklists and field notes were used during the observations. The checklists allowed the observer to record the presence or absence of predetermined indicators during the observation sessions. The field notes, on the other hand, served as a means to document additional observations, insights, and contextual information that emerged during the classroom observations. The selection of observation sites and participants followed a purposive sampling strategy. Before the observations occurred, informed consent was obtained from the school administration, teachers, and students involved in the study. The researcher visited the selected classes to establish rapport with the teachers and better understand the classroom context. This allowed the observer to become familiar with the daily routines, instructional materials, and available technology in the classrooms, thus ensuring a more accurate interpretation of the observed events.

During the observations, the observer paid close attention to various aspects of the instructional practices. They observed how teachers incorporated CT into their lessons, such as through problem-solving activities or the use of algorithms. The observer also examined how students engaged and motivated in the lesson. The observer diligently recorded their observations using the checklists, marking the presence or absence of specific indicators related to CT integration. They also took detailed field notes, documenting any additional insights or observations not covered by the predetermined indicators. These field notes provided valuable context and helped capture a more comprehensive picture of the classroom dynamics and instructional strategies.

### 3.5.4. Interview

The interviews were conducted as part of the data collection process to gather in-depth information and insights from participants regarding integrating CTE into ME in senior primary schools. This section describes the interview process, the development of the interview guide and interview protocol, and the sampling method and criteria for selecting participants.

The process of conducting interviews was carefully designed to create a conducive environment for participants to share their thoughts and experiences freely. Each interview followed a one-on-one format, providing a comfortable, confidential setting that encouraged open communication. Before the interviews, participants were given comprehensive information about the study's purpose and objectives. They were informed that their involvement in the interviews was entirely voluntary, and their consent was sought to ensure their willingness to participate and contribute their perspectives to the research. The interviews were scheduled at mutually convenient times and locations to accommodate the participants' schedules. This consideration aimed to minimize distractions and maintain privacy, allowing participants to focus on the interview without interruptions.

The duration of each interview varied between 5 to 10 minutes. This timeframe was chosen to balance obtaining sufficient information from participants and respecting their time constraints. One TA who followed a standardized protocol was appointed to help conduct the interview with the selected participants. This approach ensured consistency and reliability across all interviews, minimizing potential biases affecting data collection. The researcher guided the TA to employ active listening techniques during the interviews to understand and engage with participants attentively. Open-ended questions were posed to elicit detailed responses, encouraging participants to reflect upon their opinions and share personal experiences related to the topic of study. The researcher guided the TA to actively avoid leading or suggestive questions that could influence the participants' responses, striving to maintain objectivity and gather authentic insights. To enhance the quality and accuracy of the data, the interviews were audio-recorded with the participant's permission. This practice allowed the researcher to refer back to the recordings during the data analysis phase, ensuring the fidelity of participants' statements and enabling a thorough examination of the collected information.

Following the interviews, the audio recordings were transcribed verbatim, capturing participants' responses in a written format. These transcriptions were carefully reviewed and anonymized to ensure the confidentiality of the participants' identities. Any identifying information was removed or replaced with pseudonyms, safeguarding their privacy and anonymity. The data collected from the interviews served as valuable qualitative material for the research study. It provided unique insights into participants' perspectives, opinions, and experiences related to the topic under investigation. The researchers thoroughly analyzed the transcriptions, identifying patterns, themes, and key findings to draw meaningful conclusions and contribute to the existing knowledge in the field.

Besides the principal and four STEAM curriculum coordinators were interviewed, due to time constraints, only 10 students were sampled to complete the interview. To ensure a representative sample, a stratified random sampling method was employed. The population was divided into 3 different strata based on the performance of the students in CT and ME in the past. Each stratum randomly 3 to 4 participants for the survey. This sampling method aimed to provide a balanced representation of the stakeholders involved.

### 3.6 Data Handling and Management

Following the conclusion of the observation sessions, great care was taken to ensure that the collected data underwent a series of rigorous procedures to guarantee proper handling and management. For the quantitative survey data, a meticulously designed coding scheme was created to categorize and code the observations that had been recorded using the checklists. This coding process involved assigning numerical codes to different categories and indicators identified in the observations. Subsequently, the coded data were entered into a computerized database, facilitating further analysis. As for the qualitative interview data, a transcription process was diligently carried out to convert the audio recordings of the interviews into written text. These transcriptions were conducted by the TA who adhered to strict guidelines, ensuring the utmost accuracy and confidentiality. All identifying information was meticulously removed to safeguard the participants' identities, and pseudonyms were utilized in the transcripts.

To organize and analyze the observational data, the field notes were meticulously reviewed and compiled into a comprehensive dataset. This dataset encompassed detailed descriptions of the observed classroom practices, interactions, and instances of CT integration. The data were meticulously organized based on the identified categories and indicators from the observational protocol, thereby enabling a systematic and structured analysis. Throughout the entirety of the data handling and management procedures, the highest level of confidentiality and data security was upheld. The researcher maintained unwavering adherence to ethical guidelines, ensuring that all personal information and sensitive data were treated with the utmost care and handled securely and confidentially.

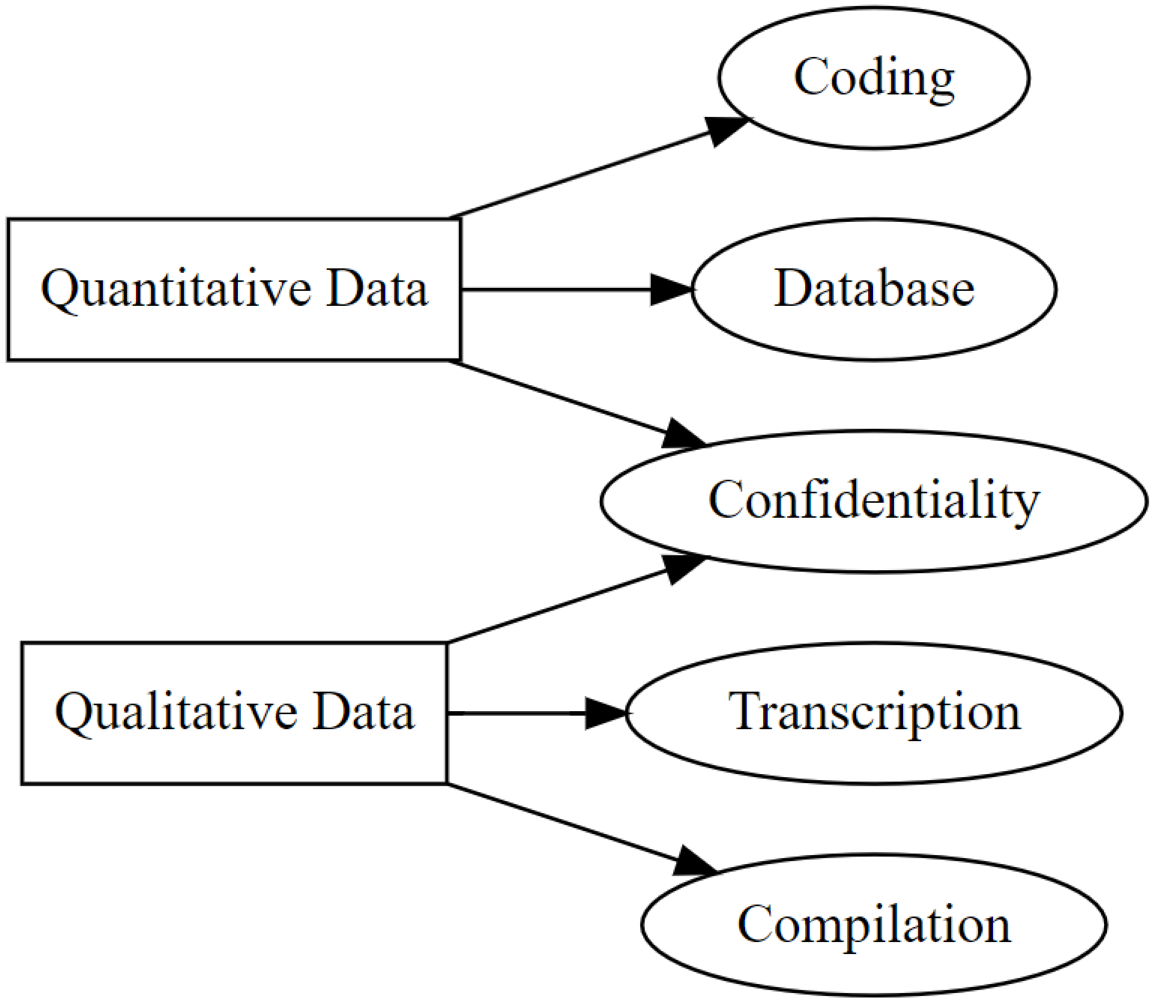



Figure 4. Data Handling Procedures: Maintaining Rigor and Ethics

## 3.7 Data Analysis Methods

### 3.7.1. Descriptive statistics

To summarize quantitative data, such as survey results, descriptive statistics may be used to examine the data. Measures like the mean, median, and mode of replies to inquiries concerning the potency of CTE in the teaching of mathematics might be included in this. A subset of statistics known as descriptive statistics is used to enumerate and characterize the features of a data collection. Descriptive statistics, which include the mean, median, and mode, may be used to summarize the data obtained when examining survey answers on the efficiency of CTE in mathematics teaching. The mean, which represents central tendency the most often, is computed by adding up all the results and dividing that by the total number of results. The mean answer would represent the average rating of all respondents, for instance, if respondents were asked to assess the success of CT schooling on a scale of 1 to 5, with 5 being the most effective.

The middle value in a data collection is called the median, which is another way to quantify central tendency. All of the answers to a question are organized from lowest to highest, and the middle value is found to determine the median. When there are exactly equal numbers of results, the median is determined by averaging the two middle values.

The most common value in a data collection is called the mode. The most popular choice would be shown by the mode answer, for instance, if respondents were asked to choose their favorite CT teaching technique from a list of possibilities in a survey question. In order to provide a quick overview of the data gathered and to draw attention to any patterns or trends in the replies, descriptive statistics might be beneficial. However, it's crucial to keep in mind that descriptive statistics merely describe the data and may not always provide insights into the underlying reasons or other variables that could be influencing the replies.

### 3.7.2. Content analysis

To find important themes and patterns in qualitative data, such as interviews with teachers and students, content analysis may be employed. This may include categorizing answers to inquiries on the advantages and difficulties using CTE in mathematics teaching to find recurring themes and patterns. A research technique called content analysis is used to examine qualitative data from sources including focus groups, interviews, and open-ended survey answers to find important themes and trends. Instead of merely summarizing or explaining the data, the objective is to thoroughly investigate and evaluate it. For instance, using content analysis to examine student and teacher interviews regarding the advantages and difficulties of integrating CTE into mathematics teaching is a good example of how this technique may be applied. In this instance, the researcher would first look over the transcripts of the interviews to get a broad grasp of the information.

The researcher would next decide on the major ideas and themes that come out of the data, such as the significance of problem-solving abilities or the difficulties of incorporating CT into current curricula. Then, these themes would be coded, or labeled, using either a preset set of categories or an inductive technique to develop brand-new categories. After that, the researcher would methodically apply these codes to the text data to find any occurrences of the codes there. This procedure may be carried either manually or with the use of coding automation tools. After the data have been coded, the researcher will examine the frequency and distribution of the codes to find recurring patterns and trends. The conclusions that may be drawn from this data on the advantages and difficulties of CTE in mathematics teaching can then be utilized to guide the creation of new research projects or educational initiatives. In general, content analysis is an effective method for examining qualitative data because it enables researchers to spot important themes and patterns in the data and make significant inferences about the current research issue.

### 3.7.3. Comparative analysis

The results of classes that have incorporated CTE into their mathematics curriculum with those that have not may be compared using comparative analysis. This can include comparing test results or other indicators of academic success between classes offering CT instruction and those that do not. A research technique called comparative analysis includes contrasting two or more groups or cases to find commonalities and differences. Comparative analysis may be used to compare the achievements of students that have integrated CTE with those that have not in the context of mathematics teaching. To compare the academic achievement of pupils in classes that have incorporated CTE into their mathematics curriculum with those that have not, for instance, a researcher may utilize comparative analysis, which could include comparing test results, grades, or other indicators of academic performance. The researcher would first separate the classes into two groups: those that have incorporated CTE into their math curriculum, and those who have not. Data on the academic achievement of students in both sets of classes would then be gathered by the researcher. The researcher would examine the data after gathering it to find any differences between the two groups' academic performance. To ascertain if there are appreciable variations in test results or grades between the two groups of schools, this investigation may use statistical tests.

The analysis' findings would then be interpreted by the researcher in order to make judgments regarding how CTE affected student achievement in mathematics teaching. For instance, the researcher could discover that pupils who attend classes with integrated CT instruction outperform those who attend classes without it when it comes to arithmetic assessments. Overall, comparative analysis is a useful method for assessing the success of integrating CTE in the teaching of mathematics. Researchers may determine the effect of CTE on academic achievement and make judgments regarding the advantages and constraints of CTE in mathematics teaching by comparing the results of classes that have incorporated CTE with those that have not.

#### 3.7.4. Case study analysis

To examine a particular school that has included CTE into their mathematics curriculum, case study analysis might be performed. This might include gathering information via surveys, observations, and interviews in order to provide a thorough account of the integration of CTE and the results obtained. In-depth examination of a particular example, such as a school that has included CTE into their mathematics curriculum, is part of the case study analysis research approach. When a researcher wishes to provide a thorough account of a phenomena or when the research issue is complicated and cannot be satisfactorily addressed by quantitative data, case study analysis might be helpful. For instance, a researcher may investigate the process of incorporating CTE into the teaching of mathematics at the school using case study analysis. The researcher would gather information using a range of techniques, including surveys of the stakeholders engaged in the integration process, interviews with teachers, administrators, and students, as well as observations of classrooms and instructional practices.

The researcher would study the data after gathering it to find major themes and emerging trends. The study would concentrate on outlining the integration of CTE, including the difficulties and triumphs faced, as well as the results attained by the students in terms of their academic achievement and other pertinent metrics. The data would then be used by the researcher to create a thorough case study report that offers a full account of the integration of CTE into mathematics teaching, the results obtained, and the lessons learned. Future research and political choices pertaining to CTE in mathematics teaching may be informed by the findings of this paper.

In general, case study analysis is an effective method for delving into difficult research topics and offering a detailed explanation of a phenomena. Case study analysis may provide important insights into the integration of CTE and the results obtained, as well as the difficulties and achievements experienced along the road, in the context of CTE in mathematics teaching.

## 3.8 Research Ethics

### 3.8.1. Informed consent

According to the ethical concept of informed consent, human subjects in study must be protected. By following this guideline, participants will be fully informed of the research's objectives, potential risks and benefits, and their ability to leave the study at any time without penalty. The principal, teachers and students who took part in this research all provided their informed permission before signing up. The researchers provided the “CONSENT TO PARTICIPATE IN RESEARCH” and “INFORMATION SHEET” in both Chinese and English to make sure that participants were fully informed and understood the information. By providing the consent forms in a range of languages, the researcher was able to ensure that subjects could decide to participate in the study in an informed manner despite any language barriers. Participants must provide their informed permission for research to be done ethically. The National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research (1979) states that informed consent is crucial for ensuring that participants understand the nature of a study, as well as any potential risks and benefits associated with their involvement (US Department of Health and Human Services, 2013). The researcher informed the participants about the study's objectives, the various data collection methods employed, and their right to withdraw from the study at any time without penalty. By sharing this information, the researchers ensured that participants were well-informed and able to make an educated decision regarding their participation in the experiment. Moreover, by offering participants the chance to ask questions before signing consent forms, the researcher confirmed that all individuals comprehended the study and were aware of any potential risks or benefits.

Specifically, the "CONSENT TO PARTICIPATE IN RESEARCH" document indicates that the participant agrees to take part in the research conducted by Dr. POON Kin Keung and Mr. LEUNG Yu Hin, Herman, who are affiliated with the Department of Mathematics and Information Technology at EdUHK as staff and students, respectively. The participant is informed that the data gathered from this research may be utilized for future studies and publications, but their personal information will remain confidential.

Furthermore, the participant is made aware of the potential benefits and risks associated with the study, as well as their right to withdraw from the research at any point without facing negative repercussions.

On the other hand, the “INFORMATION SHEET” provides an overview of this research. The sheet also describes the purpose and methodology of the research study, which involves participants answering 4 short questions in a survey or 2 interview questions with audio recording. The sheet also states that participation is voluntary and there are no potential risks associated with the study. The sheet provides contact information for the principal investigator and the Human Research Ethics Committee for further questions or concerns. Additionally, it notes that electronic copies of the research will be uploaded to online databases for internal and public access.

In short, requesting participate to complete the "CONSENT TO PARTICIPATE IN RESEARCH" and "INFORMATION SHEET" before the research begins is to ensure that the participants are fully informed about the purpose and methodology of the research study, as well as any potential risks or benefits associated with participating. The consent form serves as a legal agreement between the participant and the researcher, indicating that the participant has been fully informed and consents to participate voluntarily. The information sheet provides further details about the research study and serves as a reference for the participant. Overall, completing these documents before the research begins is an important ethical practice to ensure that participants are fully informed and protected throughout the research process.

### 3.8.2. Confidentiality

Any research project must abide by tight confidentiality regulations, particularly when collecting participants' sensitive information. All of the study's data was treated as confidential and was kept in a secure location in order to preserve the privacy of the participants. To do this, the researcher used a variety of measures to protect the confidentiality of the data obtained. All information acquired over the course of the research was kept completely confidential and secure in accordance with recognised ethical standards. To protect the participants' privacy, distinct identities were allocated, and any identifying details were omitted from the final report. The information was saved on a computer that was password-protected and only accessed by the research himself to prevent unauthorized access.

As a researcher, there is a strong responsibility to ensure that the confidentiality policy of the study was followed and that participants were fully informed about how their privacy would be protected prior to giving their consent. Participants were given the opportunity to ask any questions they had regarding confidentiality and the consequences of any breaches. To protect the confidentiality of the participants, any unique identifiers from the data used in the analysis and only used aggregated data to prevent individual responses from being identified was reviewed and removed. Great care to ensure that confidentiality was maintained throughout the study.

### 3.8.3. Risk of harm

During the informed consent procedure, participants were provided with information regarding the potential risks and benefits of participating in the study, in accordance with ethical standards for research with human participants. To minimize the risk of harm, the study involved only surveys and interviews, and participants were allowed to withdraw from the study at any time without negative consequences. In the event that participants experienced any distress, appropriate support and advice were offered to access further assistance. The study's purpose and data collection techniques were explained clearly to ensure participants understood the risks and benefits of the study, and signed consent forms were provided in both English and Chinese. To protect participant privacy, all identifying information was removed from the final report, and all data was stored on a password-protected computer accessible only to the researcher. Participants were assigned individual identities to further ensure confidentiality. To promote the well-being of participants and minimize potential risks, they were informed of the availability of counseling services and encouraged to seek further assistance if necessary.

#### **3.8.4.** Data protection

Protecting the privacy of participants' personal information is of utmost importance in research investigations. As the sole investigator and principal investigator of the study, I ensured that all personal information was securely stored and protected in compliance with applicable data protection laws and regulations in Hong Kong. Personal data was collected honestly, safely, and solely for the intended research purposes, and I was the only individual with access to the personal information gathered. To ensure that no personal information was retained after the study was completed, all data was purged and physical copies were securely destroyed. Unique IDs were assigned to each participant to maintain the confidentiality of personal data, and personal identifiers such as name and contact information were replaced with individual codes in the dataset. This step was implemented to protect the anonymity and confidentiality of participants' personal information. Using unique identifiers is a recommended approach to prevent the linkage of personal information to individual participants. No third parties had access to the personal information collected is ensured, as Hong Kong's data protection regulations prohibit the transmission of personal data to others without the consent of the individuals concerned. To further protect the privacy of individual participants, the data was only accessible to myself, and the study's findings were presented in aggregate form to prevent individual participants from being identified.

### 3.8.5. Fairness and impartiality

Ensuring fairness and objectivity in research is essential to prevent biases from impacting the study's outcomes. Prior to commencing the research, the potential for biases was identified and addressed to enhance the validity and reliability of the results. A thorough review of the relevant literature was conducted to identify potential biases that could undermine the study's validity. Objective data analysis was employed to minimize the risk of researcher bias and increase the objectivity of the study (Agabegi & Stern, 2008). Statistical tools were utilized to analyze the data gathered during the study to ensure that the conclusions were based on factual information. Conflict of interest was identified and addressed to eliminate any biases that could compromise the study's validity.

The study's sample for the interview was selected using a random selection approach to ensure the representativeness of the population of interest and increase the study's external validity (Maxfield & Babbie, 2017). Participants were chosen randomly from the population of interest, and the sample size was sufficient to obtain accurate findings. The research adhered to ethical standards and protected the rights of study participants.

### 3.8.6. Ethical approval

Any research project must include ethical issues, and this one was no different. Before the study got started, ethical permission was given by the school. This made sure that all applicable ethical and legal criteria in Hong Kong were met and that all essential measures were taken to safeguard the participants' welfare and rights. In order to guarantee that the study was carried out in an ethical and responsible way, the principles listed on the document "EdUHK's Guidelines on Ethics in Research" by EdUHK are followed, which include respect for others, beneficence, and justice. A fundamental ethical rule that stresses respecting people as autonomous agents and safeguarding those with restricted agency is respect for persons. All participants were made aware of their freedom to leave the research at any moment without repercussions in accordance with this policy. To make sure that they were aware of the study's goals, the methods used to obtain the data, and their choice to opt out, participants were given permission forms in both English and Chinese. Before completing the permission form, participants had the chance to ask any questions they had concerning the research. This was essential to make sure that the participants were making an educated choice about their involvement and were aware of the nature and scope of the research.

Another ethical concept, beneficence, is focused on enhancing participants' wellbeing and reducing any possible damage. Since only questionnaires and interviews were conducted as part of this research, the risk of harm was deemed to be very low. Participants were also permitted to leave at any moment if they were uncomfortable. However, in the case of any unpleasant feelings or discomfort, participants were given support and advice on how to get further assistance or support. This was essential to protecting the participants' wellbeing and minimizing any possible damage. The third ethical principle, justice, stresses the equitable allocation of rewards and dangers. In accordance with this premise, precautions to guarantee the study's objectivity and fairness were taken into account. Objective analysis of the data was performed, and any possible conflicts of interest were resolved. Any research effort must take data protection into account ethically. The researcher in Hong Kong complied with all applicable laws and rules governing data protection. All of the personal information gathered throughout the study was safely maintained and solely utilized for research purposes. At the conclusion of the research, all data was removed, and all physical copies were safely destroyed. This was essential to maintain the participants' anonymity and privacy as well as to prevent any exploitation of their personal information.

## 3.9 Limitations

### 3.9.1. Sample size

The degree to which study results can be generalized to a larger population is strongly influenced by the size of the research sample. The small sample size in the current research may have limited the extent to which the findings could be applied. Despite efforts to include a diverse sample, the sample size may not have been sufficient to draw firm conclusions. The study included one principal, four STEAM curriculum coordinators, and one hundred and seven pupils as participants. Although participants came from all educational levels, the sample size was still relatively small, which may have limited the ability to make definitive conclusions based on the data collected. Increasing the sample size can help to improve the precision and dependability of the results and enhance the statistical power of the study. However, it is important to assess whether the sample size is reasonable and feasible, taking into account the limitations of the research. The particular situation precluded the research from conducting a larger sample size due to logistical and resource constraints. Despite this limitation, essential preparations were made to ensure the study's validity and reliability. The results within the constraints of the research's sample size were presented, and a larger sample size may have further improved the study. Researchers must carefully consider the practicality and constraints of conducting the study when selecting the appropriate sample size.

It is important to consider the representativeness of the sample in research since it can impact the generalizability of the results. Although the current research had a diverse group of participants, it is likely that the sample was not entirely representative of Hong Kong's senior primary school pupils or mathematics teachers. This could be due to non-response bias or self-selection bias, which may result in certain groups being less likely to participate in the research. Bias is a possible limitation in any research, according to Pannucci and Wilkins

(2010), and should be considered when analyzing the findings. Despite these limitations, the current research provides valuable insights into the experiences and opinions of the participants. The results may not apply to the entire population, but they can still guide educational policies and serve as a starting point for further research. The sample's diversity, consisting of individuals from various professions and viewpoints, may have contributed to a more comprehensive understanding of the subject. To improve the sample size and ensure a more representative and diverse sample, future research can collaborate with other educational or institutional organizations. Additionally, utilizing random or stratified sampling procedures can reduce bias and improve the generalizability of the findings (Agabegi & Stern, 2008; Pannucci & Wilkins, 2010). However, increasing the sample size alone may not always address all the issues related to representativeness and bias. Therefore, research in the future should carefully analyze all components of the sampling procedure to ensure that the sample is as representative and unbiased as possible.

#### 3.9.2. Data collection methods

In research, it is crucial to select appropriate data collection methods to ensure the reliability and validity of the data collected. This research employed surveys, classroom observations, and interviews to collect data. However, each of these methods has its limitations that may impact the quality of the data collected.

Firstly, surveys were employed to gather information on students' and teachers' attitudes regarding integrating CT into ME classes. Despite taking precautions to ensure the validity of the survey questions, the survey responses may not accurately represent the participants' genuine sentiments regarding the issue.

Secondly, interviews were conducted to further study participants’ perceptions on integrating CT in ME. However, the possibility of self-reported data being skewed is a limitation of utilizing interviews as a data gathering strategy. Respondents may not correctly recollect events or may provide responses they believe to be socially acceptable.

Similarly, observations may be biased if the researcher's presence affects the participants' behavior or if the researcher's perception of the events is impacted by their own prejudices. In this study, classes with and without CT integration were observed. While observations can provide better insight into classroom dynamics, it's crucial to be aware of the possibility of bias and take precautions to minimize its influence. Another drawback of employing observations to gather data is that it can be time and resource-intensive.

Therefore, in future studies, it may be beneficial to consider hiring a larger team of researchers to perform observations to increase the trustworthiness of the data gathered. Additionally, utilizing multiple data collection methods can help to mitigate the limitations of individual methods and provide a more comprehensive understanding of the phenomenon under investigation. Researchers should also consider using triangulation, which involves comparing and contrasting data from multiple sources to increase the validity and reliability of the findings. By taking these steps, researchers can enhance the quality of their data and improve the validity and reliability of their results.

#### 3.9.3. Generalizability

Many research investigations, like this research, have the constraint of generalizability. Despite the fact that the research was carried out in Hong Kong, it is crucial to take into account the possible drawbacks of extrapolating the results to other locales or situations. The relevance and application of the results to various contexts may be impacted by variations in culture, educational systems, and resources, which give rise to this restriction. Principal, teachers, and students' attitudes, beliefs, and actions are all significantly influenced by culture. As a result, the study's conclusions could not apply to other nations or environments with distinct cultural norms and values. For instance, the expectations put on pupils and the role of teachers in various cultures may vary significantly from those in Hong Kong, which might affect the validity of the results. Future study must take into account cultural considerations and their possible impact on findings.

Additionally, educational systems differ widely throughout nations, which may limit the applicability of the study's conclusions. For instance, there may be significant differences across educational systems in the curricula, teaching techniques, and assessment strategies. The experiences and viewpoints of students and teachers may vary as a result, making it challenging to generalize the results to different situations. It is crucial to take into account these variations while evaluating the study's findings and to be aware that not all educational systems may be able to use the data. The generalizability of the results may also be impacted by resources like finance and technology. For instance, in certain nations, access to resources like textbooks, computers, and lab equipment may be restricted in schools, which may have an influence on the experiences of both students and teachers. Because of this, extrapolating the results to contexts with varying degrees of resources may be difficult. Future research needs to be aware of these variations and take into account how they can affect the study's conclusions. Future study may take a number of actions to solve the generalizability restriction. To ascertain if the results hold true in other situations, one strategy is to duplicate the research in other nations or circumstances. An alternative strategy is to carry out comparative studies that compare and contrast various cultural and educational situations. This may aid in highlighting similarities and contrasts between the experiences and viewpoints of students and teachers in various contexts. Finally, future research might examine how disparities in resources, education, and culture may affect the study's conclusions.

### 3.9.4. External factors

When doing research, it's crucial to take into account external variables that might affect the outcomes. In the context of this research, it was carried out while Hong Kong was undergoing an educational reform. This may have affected how the intervention was carried out and how successful it was, as well as how the participants responded. The timing of the research in connection to the execution of the educational reform is one possible external aspect to take into account. The research may have been carried out while the reform was just getting started, which might have influenced the findings. For instance, if the intervention was put into place before the reform was completely in place, the traditional system may have had an impact on it, making it less effective or relevant to the new environment. The amount of resources and assistance offered for the intervention's execution is another possible external element. Resources for new initiatives may be scarce during times of reform, which might have an influence on the execution and efficacy of the intervention. For instance, if there were insufficient resources available for the intervention's implementation, this may have an effect on the effectiveness of the implementation and the degree of support offered to participants.

In addition, participant attitudes and actions may have been influenced by the context of the educational reform. For instance, significant resistance to or skepticism against the change among the participants may have had an effect on their participation and responsiveness to the intervention. Similar to this, participants' perceptions and responses to the intervention may have been impacted if there was a lot of ambiguity or misunderstanding around the reform. The greater social, political, and economic context in which the educational revolution was taking place must also be considered. These extraneous factors might have affected the way the intervention was implemented, how effectively it functioned, and how the participants reacted. Imagine, for example, if at the time, the educational system was being influenced by greater social or economic issues. If such were the case, it's probable that this had an impact on the assistance and supplies made available to carry out the intervention. Overall, it is clear that external factors like educational reform may significantly affect how research is carried out, and how participants respond. While it is important to acknowledge these extraneous factors as possible study limitations, it is as important to consider them as a bigger part of the context in which the research is being done. By being aware of and taking these external elements into account, future research may more accurately understand and explain their results and make a more meaningful and nuanced contribution to the domain.

The research by Tsang et al. (2021), which sought to determine the effect of a school-based mindfulness program on the wellbeing of primary school pupils in Hong Kong, is one example of a study that faced external circumstances throughout its execution. The research was carried out during a time when educational reform was taking place, which the authors acknowledged could have had an influence on how well the intervention was implemented. The authors understood that external variables may have an influence on their research and made measures to reduce such effects, such as collaborating closely with schools to ensure that the intervention was successfully implemented and considering the larger context of the educational reform. Despite their best efforts, the authors acknowledged that outside influences may have affected the study's findings. For instance, they pointed out that the study's findings may have been impacted by changes in the study's curriculum and teaching methods as a consequence of the educational reform. The timing of the research relative to the implementation of the educational reform, they said, may have had an influence on the execution and efficacy of the intervention.

In conclusion, Tsang et al.'s (2021) research serves as an illustration of how external influences, such as educational reform, may affect the execution and efficacy of treatments as well as participant reactions. Future study may make a more nuanced and significant contribution to the area and assist to guarantee that their results are true and current by recognizing and taking these outside aspects into consideration.

## 3.10 Timeline

This sub-chapter provides a detailed timeline of the research activities conducted by the researcher throughout the course of the doctoral dissertation project. The timeline is divided into several sub-sections, each representing a different phase of the research process.

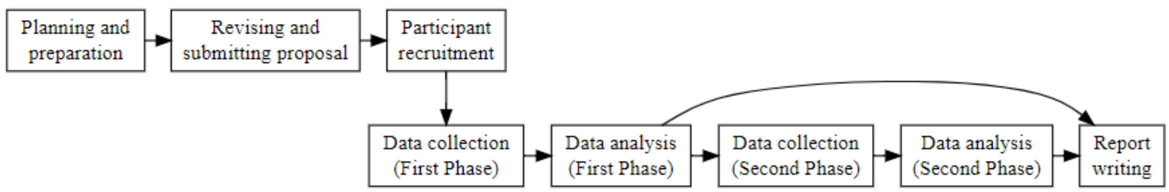



Figure 5. Research Project Timeline

### 3.10.1. Planning and preparation: Jan 2021 - July 2021 (6 months)

The research study began in January 2021. The creation of a research topic and goals was the initial phase in this procedure. This included thinking about the main research interests and identifying gaps in the body of knowledge.

After establishing the study topic, the researcher conducted a comprehensive review of the existing literature to identify key themes and issues related to CT and ME in Hong Kong. The review involved a search for relevant papers, books, and reports across multiple databases, including Google Scholar, Web of Science, and ERIC. The literature evaluation revealed gaps in the current knowledge, which informed the research design and methodology.

Subsequently, the researcher developed a study strategy based on the findings from the literature review. This involved making decisions about the sample plan, data collection techniques, and study design. Given the exploratory nature of the research, a mixed-methods approach was deemed appropriate, combining surveys, observations, and interviews to collect both quantitative and qualitative data. The study strategy also included selecting potential participants and developing data-gathering instruments such as the interview guide and survey questionnaire.

The planning and preparation phase of the study project lasted approximately six months, from January to July 2021. During this phase, the researcher focused on establishing a precise and narrowly defined research question, evaluating the existing literature, and creating a robust research strategy.

Specifically, during the planning and preparation phase, the researcher focused on laying the groundwork for the doctoral dissertation project. This involved conducting a comprehensive literature review to identify gaps in the existing research and to develop a deeper understanding of the research topic. The researcher also drafted a proposal, outlining the research questions, methodology, and expected outcomes of the study.

In addition to the literature review and proposal, the researcher also developed a chapter outline and overview, which provided a roadmap for the dissertation project. This phase allowed the researcher to establish a solid foundation for the project, ensuring that the research was well-informed, well-organized, and aligned with the overall goals of the doctoral program.

In this stage, the research area "Integrating CT into ME" is defined after literature review and research questions are generally drafted.

### 3.10.2. Submitting conference paper and journal article: Apr 2021 - Mar 2022 (12 months)

During this phase, the researcher focused on disseminating the research findings to a wider audience. This involved submitting the EdD dissertation research proposal as a conference paper to “The 25th Global Chinese Conference on Computers in Education” (GCCCE 2021), where the researcher presented the proposal and received feedback from peers and professionals in the field. The reason behind submitting and presenting the EdD dissertation research proposal to a conference served several important purposes. Firstly, presenting the proposal to a conference allowed the researcher to receive feedback from peers in the field of education. This feedback helped to refine the research questions and methodology, ensuring that the research was well-designed and likely to produce meaningful results. Secondly, presenting the proposal provided an opportunity to disseminate the research findings to a wider audience, increasing the visibility and impact of the research. Finally, besides it is beneficial to the completion of the research and degree, it also helps to establish the researcher's credibility and expertise in the field of education, which could be beneficial when applying for future research grants or academic positions.

The researcher also published a systematic literature review (SLR) journal article in the US-China Education Review, which provided a comprehensive synthesis of the existing research on the topic. In addition to the conference paper and journal article, the researcher also presented an additional literature review at the Hong Kong Mathematics Education Conference (HKMEC) 2021 conference, which helped to further refine the research questions and methodology for the doctoral dissertation. This phase not only allowed the researcher to share their work with the academic community, but also provided an opportunity for the researcher to receive valuable feedback and insights from other experts in the field, to further modify the research design.

### 3.10.3. Revising proposal: Jan 2022 - June 2022 (6 months)

During this phase, the researcher focused on refining the research proposal based on feedback received from external reviewers and peers through participating in various conferences as the conference speaker and submitting a journal article. This involved conducting another literature review to further refine the research questions and identify potential gaps in the existing research. The researcher also reviewed the proposal and made revisions as needed to ensure that it was well-supported and aligned with the overall goals of the doctoral program.

This phase was critical in ensuring that the research proposal was rigorous, well-supported, and well-positioned to address the research questions at hand. By incorporating feedback and refining the proposal, the researcher was able to ensure that the study was well-designed and likely to produce meaningful results.

### 3.10.4. Submitting proposal to the EdUHK: July 2022 - Mar 2023 (9 months)

After revising the proposal, the final draft of the proposal was sent to EdUHK to process the official proposal presentation. The researcher focused on obtaining the necessary approvals to proceed with the research. This involved presenting the proposal and defending the research methodology to a panel of experts in the field. The researcher then applied for ethics approval to ensure that the research would be conducted in an ethical and responsible manner, with appropriate measures in place to protect the privacy and well-being of the research participants.

This phase was critical in ensuring that the research was conducted in a responsible and ethical manner, and that appropriate measures were in place to protect the well-being and privacy of the research participants. By obtaining the necessary approvals and ensuring that the research was aligned with the ethical guidelines of the field, the researcher was able to proceed with confidence and clarity.

3.10.5. Participant recruitment: Oct 2022 - Dec 2022 (3 months)

Participant recruiting was next in the study timetable. The researcher focused on obtaining consent from schools and participants, and collecting data related to the literature review. The researcher started collecting data on students' academic performance in CT and ME studies separately, to establish a baseline for comparison in the later stages of the research. This phase was important in establishing the foundation for the research data, and in ensuring that the data was accurate, reliable, and well-supported.

Specifically, reaching out to the selected school and getting parents' permission to let their kids participate in the research were part of the step. The researcher contacted parents and briefed them about the goal, methods, and dangers connected with the study after receiving the required authorization from the school administration. Additionally, parents got the chance to explain any uncertainties they had regarding the research and ask any questions they had. The researcher started recruiting volunteers after securing parental approval. Between October and December 2022, a three-month period, this phase was carried out.

The researcher's goal in choosing participants was to make sure the study sample was representative of the population of interest. This involves a principal, four STEAM curriculum coordinators, two STEAM core team members, and one hundred and seven pupils. The group used purposive sampling or snowball sampling, a non-random sampling strategy that includes choosing individuals based on predetermined standards. For instance, the researcher chose participants with a closer relationship with integrating CT in ME since it was thought that this group should be included in the research. In order to have a broad and representative sample of participants, the recruiting phase of the study was essential. During this phase, there were also difficulties gaining parental agreement and some students' reluctance to participate in the study owing to worries about the study's potential effects on them. The researcher used a variety of tactics to overcome these difficulties, including informing parents and school in detail about the study, establishing a connection with participants, and resolving any issues they may have had with it. During the recruiting phase, every ethical aspect was carefully considered, including getting parents' informed agreement and protecting the participants' privacy and confidentiality. These efforts aided in ensuring the study's results' validity and dependability, which helped advance the understanding of integrating CT in ME.

### 3.10.6. Data collection (First Phase): Oct 2022 - Dec 2022 (3 months)

During the first phase of data collection, which took place from October to December 2022, the researcher focused on collecting and categorizing all related literature and existing test scores in both ME and CT. As part of this process, the researcher conducted an extensive and systematic literature review to identify relevant studies, articles, and other sources related to the CT and ME. As the school has been promoting CTE, there is a subject mainly taught about CT. The researcher also gathered existing test scores from both subjects in the selected school, which was used to inform the development of the research instrument for the study. The researcher carefully organized and categorized all of the collected data to ensure that it could be easily accessed and analyzed during the subsequent phases of the research project. Overall, the researcher was able to collect a significant amount of data during this phase, which provided a solid foundation for the remainder of the study.

### 3.10.7. Data analysis (First Phase): Jan 2023 - Mar 2023 (3 months)

The researcher focused on analyzing the collected data in the first phase using appropriate research analysis techniques in this phase. This involved examining the collected data to identify patterns and themes related to the research questions, and using software tools such as SPSS and NVivo to help with data analysis and visualization.This phase was critical in helping the researcher to establish a baseline for comparison and to identify key trends and patterns related to the research questions.

In detail, the researcher has conducted a Systematic Literature Review and document analysis through systematically analyzing and categorizing all of the curriculum guides and documents released from the EDB in Hong Kong, and existing research and study that are relevant to integrating CT into ME, to identify patterns and themes related to the research question, and generalize findings, to answer the research question “What are the roles of CT Concepts (Coding Skills), CT Practices (Problem-solving Skills) and CT Perspectives (Identity and Motivation) in ME from educators’ and students’ perspectives?”.

Additionally, the researcher also focused on answering the other research question "What is the relationship between CTE and ME?" The researcher used several data analysis techniques to analyze the relationship between the two variables and their impact on student performance. These techniques included correlation analysis, regression analysis, descriptive statistics, and inferential statistics. The researcher used these techniques to measure the strength of the relationship between student performance in mathematics and CTE, determine the factors that are most strongly associated with student performance in mathematics, identify trends and patterns in the data, and determine whether there were significant differences between groups of students. The researcher carefully analyzed the data to obtain a comprehensive understanding of the relationship between CTE and ME and their impact on student performance.

### 3.10.8. Data collection and analysis (Second Phase): Mar 2023 - May 2023 (3 months)

To study the third research question on "How students are benefiting from integrating CTE into ME? What are the effects of the integration implementation to students' performance in mathematics?", the researcher focused on analyzing the results of the CT in ME intervention in the second phase. This involved collecting and examining the data to identify the effects of the intervention on students' academic performance in CT and ME studies, and using appropriate statistical analysis techniques to assess the significance of the findings.

This phase was critical in determining the effectiveness of the CT in ME intervention, and in assessing the impact of the intervention on students' academic performance and learning motivation. By conducting a thorough analysis of the data, the researcher was able to develop more informed conclusions and recommendations, and to identify potential avenues for future research.

More specifically, the researcher collected data from the study participants using a variety of methods, including questionnaires, observations, and interviews. To begin with, the researcher administered questionnaires to gather quantitative data. The surveys were designed based on the research questions and objectives and aimed to collect information on participant demographics, attitudes toward CT in ME integration, beliefs related to the teaching and learning of CT in ME, and perceptions of the intervention's efficacy. Participants who had agreed to take part in the research, including principal, teachers, and students, were given questionnaires to complete.

In addition, the researcher conducted observations to obtain qualitative information. The observations were conducted during STEAM classes to observe the implementation of the intervention and record the methods employed by teachers and students in teaching and learning of integrating CT in ME. The researcher used an observation checklist to record the observations and also took field notes to document personal observations and comments. Finally, the researcher conducted interviews with participants to gather qualitative data on their experiences and opinions. The interviews were open-ended and semi-structured, allowing participants to express their ideas and experiences freely. The researcher conducted one-on-one interviews with teachers and students and focus groups with students. Throughout the data gathering process, the researcher followed ethical guidelines and standards.

Once the data were collected, the researcher used a data management system to organize them. The quantitative data obtained from the questionnaires were entered into a spreadsheet, and statistical software was used to analyze them. Thematic analysis was used to transcribe and analyze the qualitative data obtained from the observations and interviews. This approach involved identifying recurring themes and patterns in the data and interpreting them to gain a deeper understanding of the research issue. The researcher's data collection phase was conducted systematically, using various data collection techniques to gather both qualitative and quantitative data while adhering to ethical guidelines and regulations.

In order to elucidate the research matter, the data were systematically organized and subjected to suitable analysis techniques. By employing a blend of quantitative and qualitative data collection approaches, the researcher gained a thorough comprehension of the research subject. Additionally, adherence to ethical guidelines and standards during the data gathering process ensured that the study was conducted responsibly and ethically, with proper measures implemented to safeguard the privacy and wellbeing of the participants. The data analysis stage played a crucial role in interpreting the study's findings, ultimately leading to the formulation of insightful conclusions and recommendations.

### 3.10.9. Report writing: June 2022 - May 2023 (12 months)

During this final phase, the researcher focused on writing and revising the doctoral dissertation. This involved drafting chapters, reviewing and editing the text, and incorporating feedback from the advisor and other reviewers. The researcher also ensured that the dissertation adheres to the appropriate formatting and citation guidelines provided and guided by the EdUHK.

This phase was critical in synthesizing the research findings into a comprehensive and coherent dissertation, and in presenting the results of the research in a clear and accessible manner. By focusing on writing and revising the dissertation, the researcher was able to ensure that the research was well-supported, well-organized, and well-presented, and that the conclusions and recommendations were grounded in the empirical data.

In details, The final phase of the research timeline involved report writing, review, and editing, which took place between June 2022 and May 2023, spanning a period of twelve months. During this phase, the researcher synthesized the findings and developed a comprehensive report that detailed the results of the research. The report writing process began with a review and analysis of the data collected from surveys, observations, and interviews conducted during the data collection phase. The researcher used both qualitative and quantitative methods to analyze the data to ensure the accuracy and reliability of the findings. Key themes and patterns in the data were identified, and the findings were synthesized to answer the research questions and objectives.

The research report consisted of an introduction, literature review, methodology, results, discussion, and conclusion sections. The introduction provided an overview of the research question and objectives, and the significance of the study was discussed. The literature review section included a review of relevant literature and prior research on the topic, which helped contextualize the study. The methodology section described the methods used to collect and analyze the data, including survey questions, interview and observation protocols, and procedures used to ensure ethical treatment of participants. The results section presented the findings in a clear and organized manner, with tables, graphs, and charts used to present both qualitative and quantitative data. Quotations from participants were also included to support the conclusions and interpretations. The discussion section interpreted and analyzed the findings, providing explanations for the results and discussing the limitations of the study. The conclusion section summarized thefindings and discussed their implications for ME.

Once the first draft of the research report was completed, the researcher reviewed and edited it several times with the principal supervisor and associate supervisor. The report was organized and written clearly and concisely, meeting the formatting and submission requirements of the EdD requirement in the EdUHK. The report writing phase was critical in ensuring that the findings were presented accurately, clearly, and in a way that would be valuable to the field of ME. The finalization of the report involved a rigorous review process, helping to refine the work to a high standard.

Overall, each phase of the timeline was critical in ensuring that the research was conducted in a rigorous, systematic, and ethical manner. By taking a well-planned and well-executed approach to the research, the researcher was able to develop more informed conclusions and recommendations, and to make a meaningful contribution to the field of education. The timeline sub-chapter provides a comprehensive overview of the research activities conducted by the researcher, and serves as a roadmap for understanding the research process and the rationale behind each phase of the project.

# 4. RESULTS

## 4.1 Overview of the Study

The study's main goal was to determine if the integration of CT in ME intervention curriculum was successful in raising students' performance levels and attitudes in ME. The study used a mixed-methods research design and included a sample size of a principal, four STEAM curriculum coordinators, and one hundred and seven pupils at a primary school in Hong Kong. The data analysis processes were broken down into two phases. The first phase emphasizes answering the research question one and the second phase answers the research question two and three.

In the first phase, the researcher conducted a systematic literature review and document analysis to explore the relationship between CT and ME. The researcher then collected and analyzed students' test results in CT and ME to examine the relationship quantitatively.

In the second phase, the researcher conducted an intervention and collected additional data to further investigate the research questions. The descriptive statistics showed the distribution of the new data. The inferential statistics including independent samples t-test and ANOVA were conducted to test the hypotheses. In addition, the researcher also conducted a thematic analysis of open-ended questions to identify themes regarding the effectiveness of integrating CT in ME and challenges of implementation.

In summary, the researcher adopted a mixed methods approach to gain a comprehensive understanding of the interplay between CT and ME. Both qualitative and quantitative data were collected and analyzed to explore the relationship from different perspectives. The findings provided insights into how CT can be integrated in ME and support students' learning of mathematical concepts and skills.

The goal of the intervention was to examine the effectiveness and efficiency of integrating CT into ME, to students' learning motivation and academic performance in ME.

### 4.2 Participant Characteristics

This research aimed to investigate the effectiveness of CT instruction in primary school ME in Hong Kong. To achieve this, a diverse sample of 112 participants was recruited, consisting of a principal, four STEAM curriculum coordinators, and one hundred and seven pupils. The sample was chosen from grade 6 of English Medium Instruction (EMI) and Direct Subsidy Scheme (DSS) school in Hong Kong, where both ME and CT are two separate mandatory subjects in the selected school.

In addition, conducting research in the EMI and DSS school in Hong Kong offers several benefits. First, since the language of instruction is English, it is well-matched to conducting research in English, which can help ensure that the research is conducted effectively and accurately. Second, DSS schools have greater autonomy in their operations, including the ability to perform research, which can facilitate the research process. This autonomy allows the researcher to conduct their study more efficiently and with less bureaucratic hurdles. Finally, the researcher working as a middle manager in the school provides an advantageous position to observe and collect data from teachers and students, which can enhance the research findings and increase the validity of the study. In short, conducting research in the selected EMI and DSS school can provide a conducive environment for conducting research and may result in more accurate and relevant findings.

The student participants in grade 6 were between 10 and 12 years old. An clost number of male and female students were involved, ensuring gender balance. All students had prior experience with ME, but their prior experience with CT was limited to three years, as the selected school began promoting CTE in the school year 2019/20 and the data collection of the intervention was in the school year 2022/23. This was an intentional choice, as the study aimed to assess the impact of CT instruction on students with limited prior experience with the topic.

The teacher participants were all STEAM teachers. The four STEAM curriculum coordinators are with at least three recent years of teaching experience in CTE since the school year 2019/20 where 2 of them are Hong Kong local teachers and the rest are Native-speaking English Teachers (NET), and were recruited from the same school as the student participants. The sample included 3 male and 1 female teachers, and ranged in age from mid-twenties to late-fifties. All teachers held a bachelor's degree in education, with a major in STEAM related fields, such as science, engineering, arts and mathematics. The inclusion of experienced teachers in the sample helped to ensure that the study results were informed by a breadth of pedagogical expertise.

In conclusion, this research recruited a diverse sample of participants from an EMI and DSS primary school in Hong Kong to investigate the effectiveness of integrating CT in ME. The sample included a principal, four STEAM curriculum coordinators, and one hundred and seven pupils. The diverse sample of participants, including both male and female students and teachers, with varying educational backgrounds, adds to the richness of the study's findings. The study highlights the potential benefits of introducing CTE in primary school’s ME curriculum, such enhancing student learning motivation and academic performance in ME. The insights gained from this study could inform the development of future curricula and pedagogical practices in primary school ME in Hong Kong and potentially other similar cultural contexts.

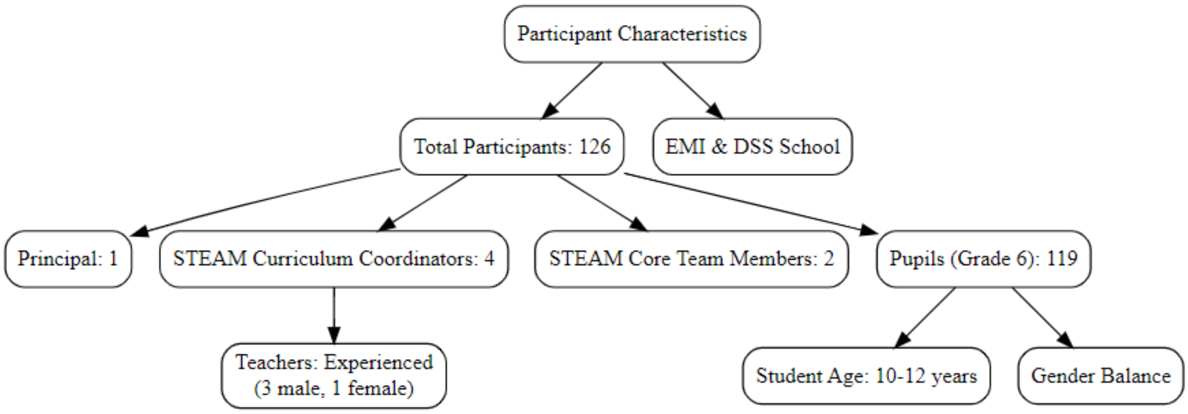



Figure 6. Participant Characteristics

## 4.3 Analysis of Data - First Phase

The researcher conducted a systematic literature review that revealed that integrating CT in ME provides effective learning opportunities to enhance students' mathematical skills and concepts. CTE can be easily embedded into mathematics curriculum and instruction. The document analysis of CT and ME curriculum frameworks showed a strong interplay between CT and ME. The summarized elements and learning contents of CT were closely related to mathematical concepts, skills, attitudes and values.

The research findings suggested that CT plays an important role in ME. CT Concepts such as operators, variables and functions are essential for developing mathematical abilities. CT Practices such as algorithmic thinking, data collection and analysis help students to apply mathematics in daily life. CT Perspectives such as persistence, comfort working with others and ability to deal with open-ended problems can build students' social-emotional learning skills in mathematics. By integrating CT in ME, students can enhance their mathematical fluency, logical reasoning skills, ability to solve problems, communication skills, creativity and other skills that are necessary for their future careers.

The researcher found a significant positive relationship between CT and ME from the correlation and regression analysis. The correlation analysis showed a moderate positive correlation ($r = 0.325$, $p < 0.001$) between students' performance in CT test (T2-CT) and ME test (T2-ME). The regression analysis also indicated that T2-CT significantly predicted T2-ME, with T2-CT explaining 36.4% of variance in T2-ME.

In summary, the study revealed a close and significant relationship between CT and ME. Integrating CT in ME is beneficial for developing students' mathematical competency and preparing them for the 21st century. The insights gained from this study could help inform the development of CT integrated mathematics curriculum and pedagogy in schools.

### 4.3.1 Systematic literature review & document analysis

One of the primary objectives of this research was to explore the interplay between CT and ME in senior primary schools. In Hong Kong, mathematics is considered a critical subject, and students are expected to develop strong mathematical skills from an early age (Li & Wang, 2017). However, the integration of CT in ME is a relatively new concept that has gained prominence in recent years. Therefore, clarifying the correlation between CT and ME is important as the foundation of this research. SLR was used to mainly answer the research question 1 "What is the relationship between CTE and ME? What are the roles of CT Concepts (Coding Skills), CT Practices (Problem-solving Skills) and CT Perspectives (Identity and Motivation) in ME from educators' and students' perspectives?".

To perform the SLR, the research has followed Kitchenham's (2004) recommended procedures, which include planning, conducting, and reporting the review. Initially, in October 2020, a preliminary search was conducted using the "Web of Science Core Collection" database. The search string consists of several components, each targeting specific aspects of the articles to be retrieved. In the topic search, the researcher looked for articles containing the keywords "Math*" (with the wildcard representing any word starting with "Math"), "Computational Thinking," and either "Primary," "Elementary," or "Junior."

These terms were combined using the "AND" and "OR" operators to ensure the articles matched all the necessary criteria. Additionally, the researcher applied filters to narrow down the search results. They limited the search to articles written in English and specifically chose articles as the document type to exclude other formats like conference papers or book chapters. Finally, the researcher specified that the search should encompass the Social Sciences Citation Index (SSCI) and Arts & Humanities Citation Index (A & HCI) for all available years in the database.

After screening the titles and abstracts, 33 articles related to CT in ME were found, out of which 27 were published in the last five years. This indicates a significant increase in the number of published studies on CT in ME since 2015. Sixteen studies were mainly selected for the content analysis as it involved teaching and learning implementation, as shown in the figure below.

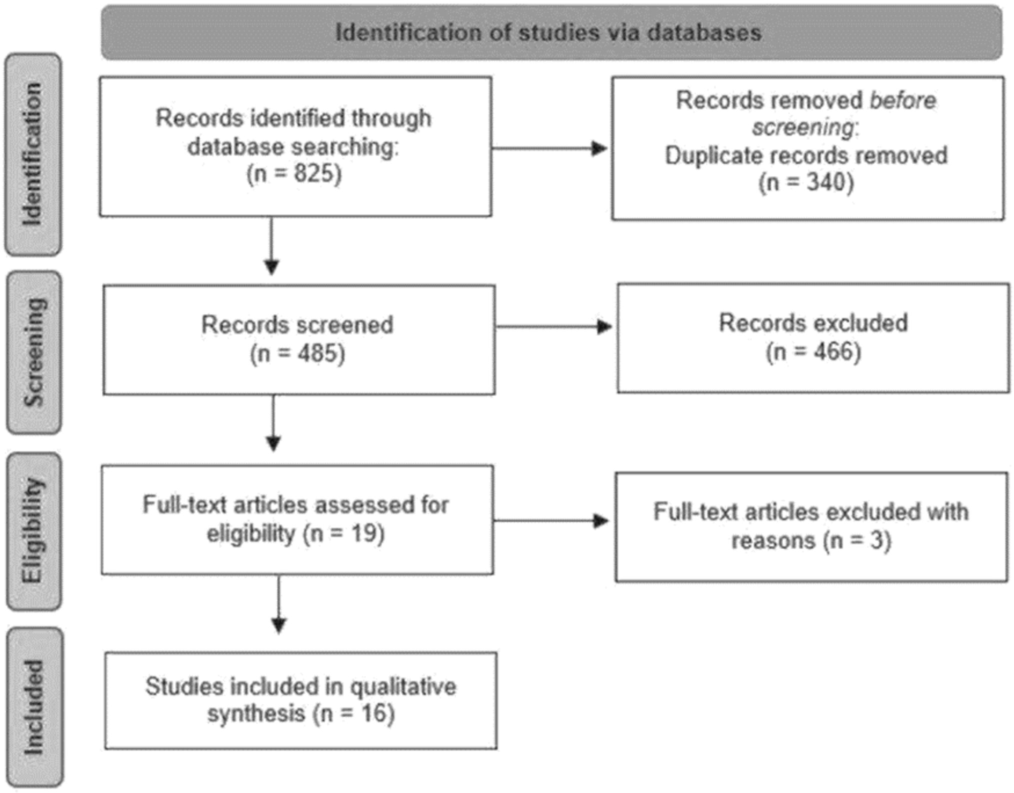



Figure 7. PRISMA Flow Diagram

The connection between CT and ME has been well-noted by several researchers. Trans-disciplinary learning, such as STEAM education, can provide effective learning opportunities to enhance students' mathematics skills and concepts. CTE can also be easily embedded into the mathematics curriculum and instruction. Integrating CT in ME can also occur in three ways: no integration, separate teaching under common themes, or an integrated subject. There is a supportive relationship between CT and ME, but the impact of CT on enhancing problem-solving skills requires further study. In summary, researchers have noted the connection between CT and ME.

After the SLR provides a solid foundation of the relationship between CT and ME are connected, the researcher started to further study the relationship between CT and ME by conducting document analysis, which is a qualitative research method used to analyze written or printed materials, such as curriculum documents, policies, textbooks, or other relevant materials, to extract information and identify themes, patterns, or relationships.

The document analysis of the various curriculum frameworks related to CT and ME has provided valuable insights. Both of the reviewed and analyzed CT and ME framework were developed by different publishers in various countries, CT curriculum framework including the EdB in HKSAR, CoolThink@JC in HKSAR, Code@SG in Singapore, Digital Promise in the US, Raspberry Pi Foundation in the UK, Let's Talk Science in Canada, and the Ministry of Education in Singapore. whereas the ME frameworks developed by the EdB in HKSAR, the Ministry of Education in Singapore, the Department for Education in the UK, and the Government of Ontario in Canada.

To summarize, the CT curriculum is commonly structured into three components, namely, CT Concepts, CT Practices and CT Perspectives, and CT Dispositions as shown below:

Table 3. Computational Thinking Curriculum Learning Objectives

| Category | Theme | Learning Objectives |
|---|---|---|
| CT Concepts | Sequences | Identifying a series of ordered steps required to solve a programming task |
| CT Concepts | Events | One thing causing another thing to happen in programming |
| CT Concepts | Conditionals | Making decisions based on certain conditions in programming |
| CT Concepts | Operators | Support for mathematical and logical expressions in programming |
| CT Concepts | Parallelism | Making things happen at the same time in programming |
| CT Concepts | Repetition (loops) | Running the same sequence multiple times in programming |
| CT Concepts | Variables | Storing information to be referenced and computed in a program |
| CT Concepts | Data | Basic ways data are stored, retrieved, and updated in programming |
| CT Concepts | Functions | Creating code blocks to modularize and abstract sequences of commands in programming |
| CT Practices | Testing & Evaluating | Ensuring that things work as intended and finding and solving problems when they arise in programming |
| CT Practices | Decomposition | Breaking down complex problems into smaller, more manageable parts in programming |
| CT Practices | Abstraction | Identifying patterns and creating generalized solutions in programming |
| CT Practices | Algorithmic Thinking | Developing a structured approach to problem-solving in programming |
| CT Practices | Debugging | Identifying and fixing errors in programming |
| CT Practices | Data collection & Analysis | Collecting and analyzing data to inform programming decisions and solutions |
| CT Practices | Data Representation | Representing data in various formats, such as text, numbers, and images, for use in programming |
| CT Perspectives | Expressing | Creating and expressing ideas through the medium of coding and programming |

| | | |
|---|---|---|
| CT Perspectives | Questioning | Asking critical questions about the social, ethical, and cultural implications of technology and computing |
| CT Perspectives | Innovating | Creating new and innovative solutions to problems using technology and computing |
| CT Perspectives | Persistence | Persevering through challenges and setbacks in programming |
| CT Perspectives | Comfort working with others | Collaborating effectively with others in programming |
| CT Perspectives | Comfort with trial and error | Being comfortable with making mistakes and learning from them in programming |
| CT Perspectives | Flexibility | Adapting to changing requirements and circumstances in programming |
| CT Perspectives | Creativity | Generating novel ideas and solutions in programming |
| CT Perspectives | Ability to tolerate ambiguity | Dealing with uncertainty and incomplete information in programming |
| CT Perspectives | Ability to deal with open-ended problems | Addressing problems without a clear solution in programming |
| CT Perspectives | Confident dealing with complexity | Tackling complex problems with confidence in programming |
| CT Perspectives | Inquisitiveness/curiosity | Being curious and asking questions to deepen understanding in programming |

For the ME framework in Hong kong, Singapore, the UK and Canada, the researcher focused on summarizing the curriculum aims as listed in the table below:

1. Develop students' mathematical abilities, including conceptualization, reasoning, problem formulation and solving, and appreciation of mathematics' aesthetic and cultural aspects.

2. Equip students with necessary mathematical skills for solving daily life problems, such as identifying numerical relationships, using appropriate measurement tools, and conducting investigations.
3. Improve students' logical reasoning abilities by choosing and utilizing classification and generalization criteria, pursuing an investigative approach, and constructing an argument, justification, or proof using mathematical terminology.
4. Enable students to communicate effectively using mathematical terms and symbols.
5. Provide a foundation in mathematics essential for careers in science, technology, engineering, financial literacy, and most forms of employment.
6. Improve students' proficiency in basic mathematical concepts by engaging them in progressively challenging problems, fostering both conceptual comprehension and swift, precise application of knowledge.
7. Equip students with the skills to tackle both routine and non-routine problems with growing complexity, including decomposing problems into more manageable steps and displaying persistence in finding solutions.
8. Integrate social-emotional learning competencies within ME, empowering students to adopt a positive attitude towards problem-solving, learn from errors, manage anxiety, and develop a strong self-image as competent math learners.
9. Foster creativity and innovation in students by encouraging critical questioning of technology and computing social, ethical, and cultural implications, generating novel ideas and solutions in programming, and promoting the creation of new and innovative solutions to problems using technology and computing.

Throughout the document analysis, this is found that there is a strong interplay between CT and ME. The summarized elements and learning content of CT are closely related to mathematical concepts, skills and attitude and value. The table below shows the marching CT learning content with the aim of the summarized mathematics curriculum.

Table 4. Aims of ME Curriculum and CTE Curriculum Learning Content

| **Mathematics Education** | **Computation Thinking Education** |
|---|---|
| Develop mathematical abilities | Operators, Variables, Functions, Data collection & Analysis, Data Representation, Creativity |
| Apply mathematics to daily life | Algorithmic Thinking, Data collection & Analysis |
| Enhance logical reasoning skills | Conditionals, Testing & Evaluating, Decomposition, Abstraction, Algorithmic Thinking, Debugging |
| Effective communication using mathematical terms and symbols | Sequences, Functions |
| Provide foundation for future careers | Operators, Data, Data collection & Analysis, Data Representation |
| Develop fluency in mathematics | Sequences, Repetition (loops) |
| Solve routine and non-routine problems | Sequences, Conditionals, Repetition (loops), Testing & Evaluating, Decomposition, Abstraction, Algorithmic Thinking, Debugging, Creativity |
| Build social-emotional learning skills | Perseverance, Ease in collaborating with others, Familiarity with trial and error, Adaptability, Capacity to handle ambiguity, Proficiency in addressing open-ended problems, Confidence in managing complexity, Inquisitiveness and curiosity. |
| Foster creativity and innovation | Parallelism, Variables, Functions, Testing & Evaluating, Abstraction, Algorithmic Thinking, Debugging, Expressing, Questioning, Innovating, Creativity |

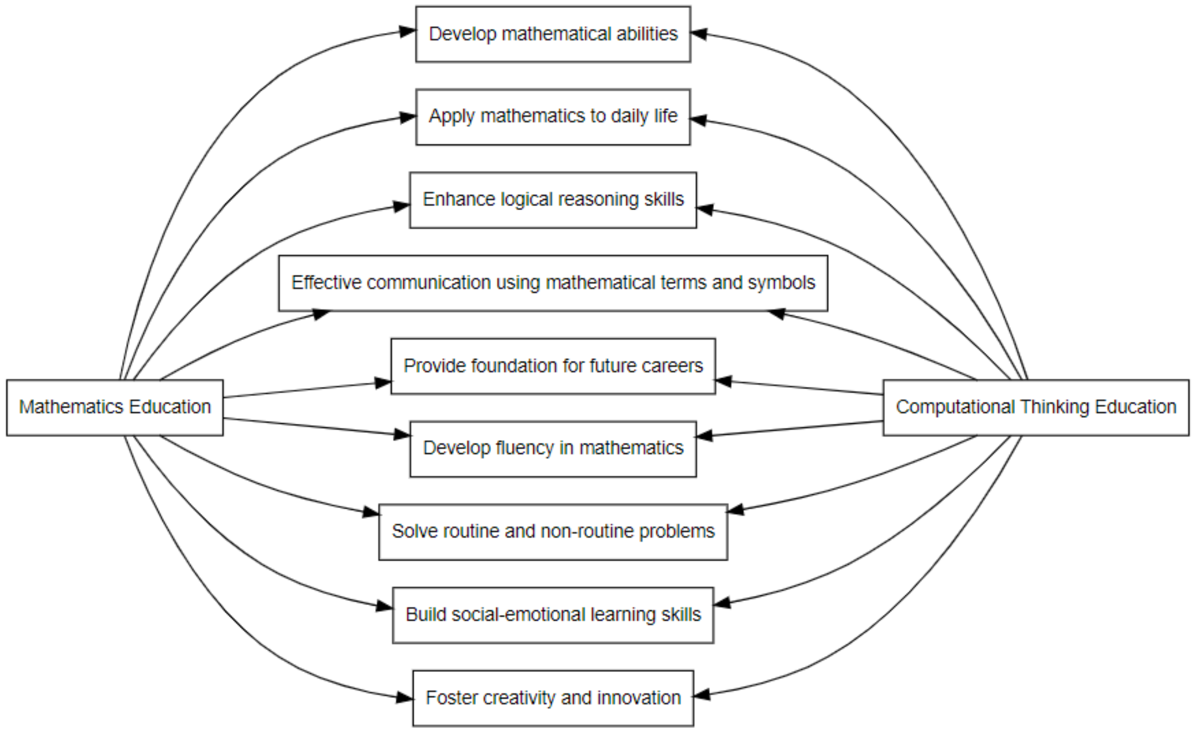



Figure 8. Holistic Learning Outcomes of CT and ME

1. Develop mathematical abilities

- CT Concepts: Operators (support for mathematical and logical expressions in programming)

  Example: Utilizing programming to compute the area or perimeter of a shape, employing mathematical operations like addition, subtraction, multiplication, and division.

- CT Concepts: Variables (storing information to be referenced and computed in a program)

  Example: Using programming to store and manipulate numerical values, such as storing the value of pi in a variable and using it in calculations.

- CT Concepts: Functions (creating code blocks to modularize and abstract sequences of commands in programming)

Example: Using programming to create a function that calculates the volume of a cube, which can be used repeatedly throughout a program.

- CT Practices: Data collection & Analysis (collecting and analyzing data to inform programming decisions and solutions)
  Example: Using programming to collect and analyze data from a survey about favorite colors, and using that data to create a pie chart or a bar graph.

- CT Practices: Data Representation (representing data in various formats, such as text, numbers, and images, for use in programming)
  Example: Using programming to represent data in different formats, such as converting numerical data into a bar graph or a line graph.

2. Apply mathematics to daily life

- CT Practices: Algorithmic Thinking (developing a structured approach to problem-solving in programming)
  Example: Using programming to create a budgeting tool that calculates expenses and income, helping to manage daily finances more effectively.

- CT Practices: Data collection & Analysis (collecting and analyzing data to inform programming decisions and solutions)
  Example: Using programming to collect and analyze data about daily exercise routines, and using that data to create personalized workout plans.

3. Enhance logical reasoning skills

- CT Concepts: Conditionals (making decisions based on certain conditions in programming)
  Example: Using programming to create a game where the player must make decisions

based on certain conditions, such as choosing the correct math operation to solve a problem.

- CT Practices: Testing & Evaluating (ensuring that things work as intended and finding and solving problems when they arise in programming)
  Example: Using programming to test and evaluate a program that solves math problems, identifying and fixing any errors that arise.

- CT Practices: Decomposition (breaking down complex problems into smaller, more manageable parts in programming)
  Example: Using programming to break down a complex math problem into smaller, more manageable steps, making it easier to solve.

- CT Practices: Abstraction (identifying patterns and creating generalized solutions in programming)
  Example: Using programming to identify patterns in a set of math problems, and create a generalized solution that can be applied to similar problems.

4. Effective communication using mathematical terms and symbols

- CT Concepts: Sequences (identifying a series of ordered steps required to solve a programming task)
  Example: Using programming to create a sequence of steps to solvea math problem, and using mathematical terms and symbols to communicate those steps clearly.

- CT Concepts: Functions (creating code blocks to modularize and abstract sequences of commands in programming)
  Example: Using programming to create a function that converts fractions to decimals,

and using that function to communicate the process of conversion using mathematical terms and symbols.

5. Provide foundation for future careers

- CT Concepts: Data (basic ways data are stored, retrieved, and updated in programming)

  Example: Using programming to create a database of mathematical formulas, which can be accessed and updated by users to support their work in math-related careers.

- CT Practices: Data collection & Analysis (collecting and analyzing data to inform programming decisions and solutions)

  Example: Using programming to collect and analyze data on customer preferences and behaviors, which can inform decision-making in a math-related business.

6. Develop fluency in mathematics

- CT Concepts: Sequences (identifying a series of ordered steps required to solve a programming task)

  Example: Using programming to create a sequence of steps to solve a math problem, and practicing that sequence repeatedly to develop fluency and speed.

- CT Concepts: Repetition (loops) (running the same sequence multiple times in programming)

  Example: Using programming to create a loop that runs a math problem multiple times, helping to reinforce concepts and develop fluency.

7. Solve routine and non-routine problems

- CT Concepts: Sequences (identifying a series of ordered steps required to solvea programming task)

Example: Using programming to create a sequence of steps to solve a complex math problem, breaking it down into smaller, more manageable steps.

- CT Concepts: Conditionals (making decisions based on certain conditions in programming)
  Example: Using programming to create a game that requires the player to make decisions based on certain conditions, such as choosing the correct math operation to solve a problem.

- CT Concepts: Repetition (loops) (running the same sequence multiple times in programming)
  Example: Using programming to create a loop that runs a math problem multiple times, helping to reinforce concepts and develop fluency.

- CT Practices: Testing & Evaluating (ensuring that things work as intended and finding and solving problems when they arise in programming)
  Example: Using programming to test and evaluate a program that solves math problems, identifying and fixing any errors that arise.

- CT Practices: Decomposition (breaking down complex problems into smaller, more manageable parts in programming)
  Example: Using programming to break down a complex math problem into smaller, more manageable steps, making it easier to solve.

- CT Practices: Abstraction (identifying patterns and creating generalized solutions in programming)
  Example: Using programming to identify patterns in a set of math problems, and create a generalized solution that can be applied to similar problems.

- CT Perspectives: Creativity (generating novel ideas and solutions in programming)
  Example: Using programming to create a game that requires the player to use creative problem-solving skills to solve math problems, such as finding alternative methods to solve a problem or using different mathematical concepts to arrive at a solution.

8. Build social-emotional learning skills

- CT Perspectives: Persistence (persevering through challenges and setbacks in programming)
  Example: Using programming to solve a challenging math problem, and persisting through errors and setbacks to arrive at a solution.

- CT Perspectives: Comfort working with others (collaborating effectively with others in programming)
  Example: Using programming to work collaboratively with others to solve a math problem, sharing ideas and building on each other's strengths.

- CT Perspectives: Comfort with trial and error (being comfortable with making mistakes and learning from them in programming)
  Example: Using programming to experiment with different approaches to solve a math problem, and learning from mistakes and errors along the way.

- CT Perspectives: Flexibility (adapting to changing requirements and circumstances in programming)
  Example: Using programming to adapt to changing mathematical requirements, such as adjusting the formula for a problem based on new data or information.

- CT Perspectives: Ability to tolerate ambiguity (dealing with uncertainty and incomplete information in programming)

Example: Using programming to solve a math problem with incomplete or uncertain information, and tolerating ambiguity to arrive at the best possible solution.

- CT Perspectives: Ability to deal with open-ended problems (addressing problems without a clear solution in programming)
  Example: Using programming to tackle an open-ended math problem, exploring different approaches and solutions to arrive at a satisfactory conclusion.

- CT Perspectives: Confident dealing with complexity (tackling complex problems with confidence in programming)
  Example: Using programming to tackle a complex math problem, breaking it down into smaller, more manageable steps and approaching it with confidence and determination.

- CT Perspectives: Inquisitiveness/curiosity (being curious and asking questions to deepen understanding in programming)
  Example: Using programming to explore a mathematical concept or theory, asking questions and seeking answers to deepen understanding and knowledge.

9. Foster creativity and innovation

- CT Concepts: Parallelism (making things happen at the same time in programming)
  Example: Using programming to create a game or simulation that requires parallel processes, such as simulating the movement of particles in a physics experiment.

- CT Concepts: Variables (storing information to be referenced and computed in a program)
  Example: Using programming to create a variable that represents a mathematical concept or theory, and using it in creative and innovative ways.

- CT Concepts: Functions (creating code blocks to modularize and abstract sequences of commands in programming)
  Example: Using programming to create a function that represents a mathematical formula or concept, and using it in creative and innovative ways.

- CT Practices: Testing & Evaluating (ensuring that things work as intended and finding and solving problems when they arise in programming)
  Example: Using programming to test and evaluate a new and innovative approach to solving a math problem, identifying and fixing any errors or issues that arise.

- CT Practices: Abstraction (identifying patterns and creating generalizedsolutions in programming)
  Example: Using programming to identify patterns in a set of math problems, and creating a generalized solution that can be applied in creative and innovative ways to solve new and unique problems.

- CT Practices: Algorithmic Thinking (developing a structured approach to problem-solving in programming)
  Example: Using programming to develop a structured and innovative approach to solving a complex math problem, using algorithmic thinking to optimize and streamline the process.

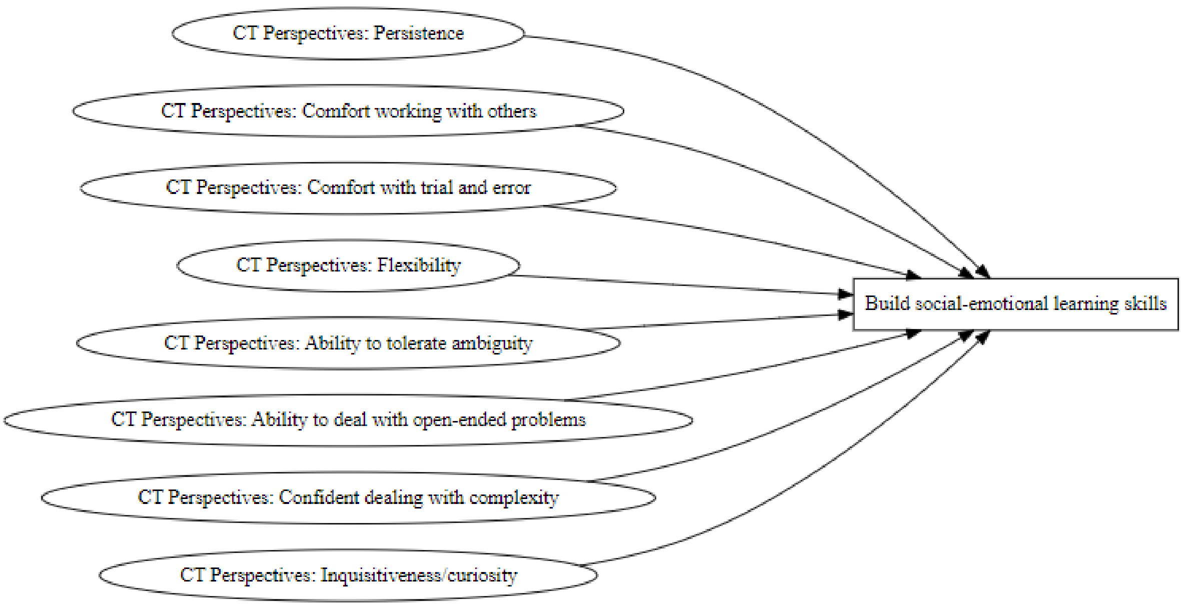
- CT Practices: Debugging (identifying and fixing errors in programming)
  Example: Using programming to debug and refine a new and innovative approach to solving a math problem, ensuring that it works as intended and produces accurate results.

- CT Perspectives: Expressing (creating and expressing ideas through the medium of coding and programming)

  Example: Using programming to express and communicate mathematical ideas and concepts in innovative and creative ways, such as creating a visual representation of a mathematical theory or concept.

- CT Perspectives: Questioning (asking critical questions about the social, ethical, and cultural implications of technology and computing)

  Example: Using programming to explore the social, ethical, and cultural implications of mathematical concepts and theories, asking critical questions and proposing innovative solutions to address any issues or challenges.



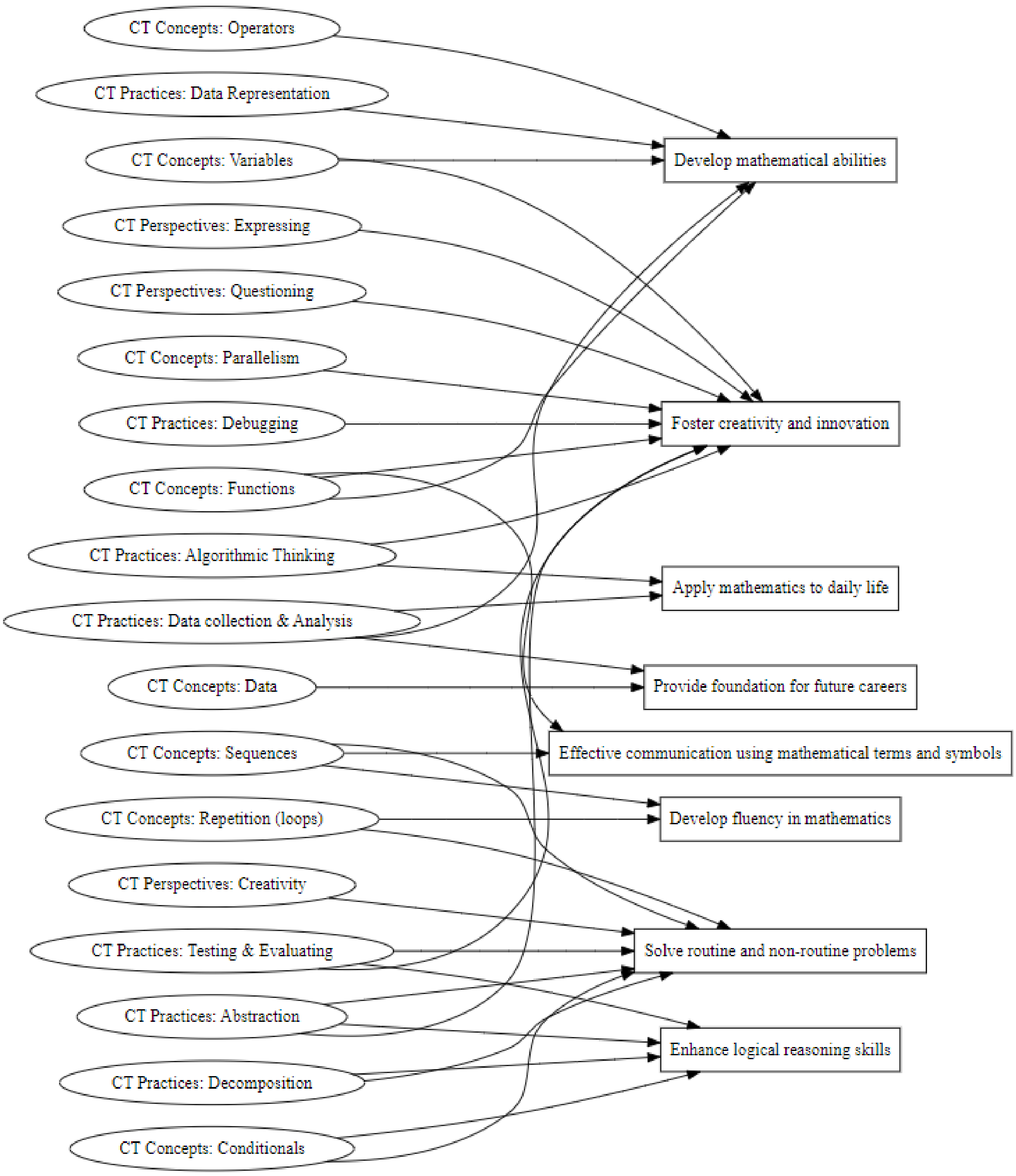



Figure 9. Interplay between Mathematical Aims and Computational Thinking Components

### 4.3.2 Descriptive statistics

Table 5. Descriptive Statistics of Term 2 CT and ME Test Score

**Descriptive Statistics**

| | N | Range | Minimum | Maximum | Mean | Std. Deviation | Variance |
|---|---|---|---|---|---|---|---|
| T2 (CT) | 107 | 38.50 | 61.50 | 100.00 | 94.4687 | 8.26275 | 68.273 |
| T2 (ME) | 107 | 87.50 | 12.50 | 100.00 | 85.3832 | 13.50726 | 182.446 |
| Valid N (listwise) | 107 | | | | | | |

The research has collected students' test results in both CT examination (T2-CT) and ME examination (T2-ME) which were completed in the school year 2022/23 to ensure that the data is reliable and timely. The descriptive statistics table above shows the summary statistics for the two test results. The sample size for both variables is 107, meaning that there are 107 observations for each variable. For T2-CT, the range is 38.50, meaning that the difference between the minimum value of 61.50 and the maximum value of 100.00 is 38.50. The mean value of T2-CT is 94.4687, and the standard deviation is 8.26275. The variance of T2-CT is 68.273.

For T2-ME, the range is 87.50, meaning that the difference between the minimum value of 12.50 and the maximum value of 100.00 is 87.50. The mean value of T2-ME is 85.3832, and the standard deviation is 13.50726. The variance of T2-ME is 182.446.

However, the descriptive statistics table does not provide any direct insight about the correlation between T2-CT and T2-ME. It only presents basic information about the distribution of the two variables, such as their range, minimum and maximum values, mean, standard deviation, and variance. Therefore, correlation analysis and regression analysis were conducted to examine the relationship between CT and ME.

### 4.3.3 Correlation analysis

The researcher conducted a correlation analysis to compare the test results of 107 students (N=107) on their CT test (T2-CT) and ME test (T2-ME) to further study the research question 1 "What is the relationship between CTE and ME?" after the systematic literature review and document analysis.

The correlation coefficients presented in the table signify the strength and direction of the linear relationship between the two variables: T2-CT and T2-ME, which represent students' performance on the CT test and ME test, respectively. A correlation coefficient of 1 denotes a perfect positive correlation, while a coefficient of -1 signifies a perfect negative correlation. A coefficient of 0 implies no correlation between the variables (Taylor, 1990).

As expected, the Pearson correlation coefficient between T2-CT and itself is 1. The coefficient between T2-CT and T2-ME is 0.614, suggesting a strong positive correlation between these variables. With a p-value of less than 0.001, this correlation is deemed statistically significant, indicating a meaningful linear relationship between T2-CT and T2-ME based on the obtained results.

Both variables have a sample size of 107, meaning there are 107 observations for each variable. The correlation coefficient of 0.614** is significant at the 0.01 level (2-tailed), indicating that the probability of obtaining this result by chance is very low. Therefore, the researcher concluded that there is a significant linear relationship between T2-CT and T2-ME based on the results obtained.

The correlation analysis results provide strong evidence to support the notion that students who perform well in CT examination also tend to perform well in ME examination. This finding underscores the importance of integrating CTE into ME, as it suggests that teaching computational thinking skills may have a positive impact on students' mathematics performance. Further research, such as experimental studies or longitudinal investigations, may be conducted to explore the causal relationship between CTE and ME and to better understand the underlying mechanisms that drive this correlation.

Table 6. Correlation between Term 2 CT Test Score and ME Test Score

**Correlations**

| | | T2 (CT) | T2 (ME) |
|---|---|---|---|
| T2 (CT) | Pearson Correlation | 1 | .614** |
| | Sig. (2-tailed) | | <.001 |
| | N | 107 | 107 |
| T2 (ME) | Pearson Correlation | .614** | 1 |
| | Sig. (2-tailed) | <.001 | |
| | N | 107 | 107 |

**. Correlation is significant at the 0.01 level (2-tailed).

### 4.3.4 Regression analysis

Besides conducting the correlation analysis using the Pearson correlation coefficient, a regression analysis was also performed by the researcher to examine the relationship between CT and ME.

Table 7. Regression Model Summary

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .614[a] | .377 | .371 | 10.71353 |

a. Predictors: (Constant), T2 (CT)

The R-squared value of 0.377 indicates that 37.7% of the variance in the ME test (T2-ME) can be explained by the CT test (T2-CT). The adjusted R-squared value of 0.371 suggests that the model is a good fit for the data, taking into account the sample size and the number of independent variables. The standard error of the estimate of 10.71353 indicates that the predicted values are, on average, within 10.71353 units of the actual values (Cameron & Windmeijer, 1997).

The regression analysis suggests that there is a significant relationship between T2-CT and T2-ME, with CT test performance explaining approximately 37.7% of the variance in ME test performance. This finding further supports the importance of incorporating computational thinking skills into mathematics education, as it demonstrates that students' CT abilities may have a considerable impact on their ME performance.

Table 8. ANOVA Table for Term 2 CT and ME Test Score

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 7287.417 | 1 | 7287.417 | 63.490 | <.001[b] |
| | Residual | 12051.872 | 105 | 114.780 | | |
| | Total | 19339.290 | 106 | | | |

a. Dependent Variable: T2 (ME)

b. Predictors: (Constant), T2 (CT)

The ANOVA table reveals that the regression model is significant, as evidenced by an F-value of 63.490 and a p-value of less than 0.001. This suggests that the model adequately fits the data and that the regression coefficients are meaningfully different from zero (Tabachnick & Fidell, 2007).

The results of the correlation, regression, and ANOVA analyses collectively provide strong evidence for a significant relationship between students' performance in CT examinations (T2-CT) and ME examinations (T2-ME). The positive correlation between the two variables, as well as the significant regression model, demonstrates that students who excel in CT tend to perform well in ME as well. This finding highlights the importance of integrating computational thinking skills into mathematics education, as it suggests that enhancing students' computational thinking abilities may lead to improved performance in mathematics.

Table 9. Coefficient Table

**Coefficients**[a]

| Model | | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | -9.414 | 11.942 | | -.788 | .432 |
| | T2 (CT) | 1.003 | .126 | .614 | 7.968 | <.001 |

a. Dependent Variable: T2 (ME)

The coefficient table shows that the coefficient of the CT test (T2-CT) is 1.003, indicating that for every one unit increase in the CT test, the score of the ME test (T2-ME) increases by 1.003. The p-value of less than 0.001 suggests that this coefficient is significantly different from zero, indicating a significant linear relationship between the CT test and ME test.

The regression analysis output shows that T2-CT is a significant predictor of T2-ME. The regression equation is: T2-ME = -9.414 + 1.003(T2-CT)

The regression equation demonstrates that an increase in CT test performance is associated with an increase in ME test performance. This finding underscores the importance of integrating computational thinking skills into mathematics education, as it suggests that enhancing students' computational thinking abilities may lead to improved performance in mathematics.

## 4.4 Analysis of Data - Second Phase

In this phase, an intervention program was conducted from 8th March, 2023 to 12th May, 2023 as the term 3 of the selected school started on 8th March, 2023. The researcher conducted the research in a school that implemented heterogeneous grouping in its classrooms, which is in contrast to homogeneous grouping, where students are grouped based on their similar abilities or performance levels. In this setting, students of various abilities and backgrounds were equally distributed across four different classes, rather than being grouped according to their ability levels.

### 4.4.1 Descriptive statistics

Table 10. Descriptive Statistics of 4 Classes in Term 2 ME Test Score

**Descriptive Statistics**

| Class | | N | Range | Minimum | Maximum | Mean | Std. Deviation | Variance |
|---|---|---|---|---|---|---|---|---|
| Class A | T2 (ME) | 27 | 37.50 | 62.00 | 99.50 | 88.3704 | 8.55142 | 73.127 |
| | Valid N (listwise) | 27 | | | | | | |
| Class B | T2 (ME) | 26 | 87.00 | 12.50 | 99.50 | 79.0000 | 19.22862 | 369.740 |
| | Valid N (listwise) | 26 | | | | | | |
| Class C | T2 (ME) | 26 | 35.00 | 65.00 | 100.00 | 87.5962 | 10.15187 | 103.060 |
| | Valid N (listwise) | 26 | | | | | | |
| Class D | T2 (ME) | 28 | 44.50 | 55.50 | 100.00 | 86.3750 | 12.41685 | 154.178 |
| | Valid N (listwise) | 28 | | | | | | |

The table above shows the descriptive statistics for four classes (A, B, C, and D) in grade 6 in the selected school that implemented heterogeneous grouping. The data focuses on a variable called T2 (ME) which represents students' mathematics academic performance before the intervention. The following provides a more detailed interpretation:

Class A: There are 27 students in this class. The minimum score is 62.00, and the maximum score is 99.50. The average (mean) score for this class is 88.37 with a standard deviation of 8.55, indicating a relatively small spread in the scores.

Class B: This class consists of 26 students. The minimum score is 12.50, and the maximum score is 99.50. The mean score for Class B is 79.00, and the standard deviation is 19.23, showing a larger spread in the scores compared to Class A.

Class C: There are 26 students in Class C. The minimum score is 65.00, while the maximum score is 100.00. The mean score for this class is 87.60, with a standard deviation of 10.15, indicating a moderate spread in the scores.

Class D: This class has 28 students. The minimum score is 55.50, and the maximum score is 100.00. The mean score for Class D is 86.38, and the standard deviation is 12.42, showing a relatively larger spread in the scores compared to Classes A and C.

The data suggests that there is some variation in student performance across the four classes before the intervention, with Class B having the lowest average score and the largest spread in scores, while Class A and Class C have relatively higher average scores and smaller spreads. The data spreads reflect students' learning differences and the impact of heterogeneous grouping on their academic performance in mathematics.

After providing a 2-month CT curriculum as the intervention to class A and class B, where class C and class D did not, the researcher collected the ME test scores for Term 3. The Term 3 descriptive statistics are as follows:

Table 11. Descriptive Statistics of 4 Classes in Term 3 ME Test Score

**Descriptive Statistics**

| Class | | N | Range | Minimum | Maximum | Mean | Std. Deviation | Variance |
|---|---|---|---|---|---|---|---|---|
| Class A | T3 (ME) | 27 | 19.00 | 81.00 | 100.00 | 90.4444 | 6.27163 | 39.333 |
| | Valid N (listwise) | 27 | | | | | | |
| Class B | T3 (ME) | 26 | 69.00 | 31.00 | 100.00 | 81.7308 | 14.14088 | 199.965 |
| | Valid N (listwise) | 26 | | | | | | |
| Class C | T3 (ME) | 26 | 19.00 | 76.00 | 95.00 | 84.0000 | 4.68188 | 21.920 |
| | Valid N (listwise) | 26 | | | | | | |
| Class D | T3 (ME) | 28 | 35.00 | 65.00 | 100.00 | 85.7143 | 11.58178 | 134.138 |
| | Valid N (listwise) | 28 | | | | | | |

Class A: After the intervention, the mean score increased from 88.37 to 90.44, and the standard deviation decreased from 8.55 to 6.27. This indicates an improvement in overall performance and a smaller spread in scores for Class A.

Class B: The mean score for Class B increased from 79.00 to 81.73 after the intervention. The standard deviation also decreased from 19.23 to 14.14. This demonstrates an improvement in performance and a reduction in score variation.

Class C: Without the intervention, the mean score for Class C decreased slightly from 87.60 to 84.00, and the standard deviation also decreased from 10.15 to 4.68. This suggests a small decline in overall performance and reduced score variation.

Class D: For Class D, the mean score dropped from 86.38 to 85.71 without the intervention, and the standard deviation slightly decreased from 12.42 to 11.58. This indicates a decline in overall performance and a small reduction in score variation.

The researcher observed that the CT curriculum intervention led to improvements in the test scores for Classes A and B, which received the intervention. Both classes experienced an increase in mean scores and a decrease in score variability. In contrast, Classes C and D, which did not receive the intervention, showed a decline in mean scores and a reduction in score variability.

However, it is important to note that these conclusions are based on descriptive statistics, and further analysis, such as inferential statistics, would be required to draw more meaningful conclusions about the effectiveness of the CT curriculum intervention on students' academic performance in mathematics.

In addition to analyzing the test scores, the researcher also conducted a survey to evaluate the effectiveness of the CT curriculum intervention from the students' perspective and perception. The target participants of the survey were all 61 student participants (N=53) who were in the experimental group (Class A & Class B). The survey results would provide insights into how the students viewed the integration of CT curriculum into their mathematics learning and whether it had a positive influence on their engagement, understanding, and confidence in the subject.

There are four questions in the survey focusing on addressing the research question 3, which are:

1. How much do you enjoy participating in computational thinking activities (Vinci Bot) during your mathematics lessons?

2. Do you feel that computational thinking activities help you better understand mathematical concepts?
3. Does participating in computational thinking activities make you more motivated to learn mathematics?
4. Would you be interested in participating in more coding activities in your mathematics lessons in the future?

Table 12. Descriptive Statistics of Survey Responses

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| How much do you enjoy participating in computational thinking activities (Vinci Bot) during your mathematics lessons? | 53 | 2 | 5 | 4.30 | .638 |
| Do you feel that computational thinking activities help you better understand mathematical concepts? | 53 | 2 | 5 | 4.38 | .740 |
| Does participating in computational thinking activities make you more motivated to learn mathematics? | 53 | 2 | 5 | 4.19 | .590 |
| Would you be interested in participating in more coding activities in your mathematics lessons in the future? | 53 | 2 | 5 | 4.30 | .638 |
| Valid N (listwise) | 53 | | | | |

Based on the data analysis of the survey conducted among 53 participants in the experimental group who received the intervention of integrating CT activities into mathematics lessons, the following conclusions and findings can be drawn:

The participants generally enjoyed participating in CT activities (Vinci Bot) during their mathematics lessons (Mean = 4.30, Std. Deviation = 0.638). This suggests that the integration of CT activities was well received by the students.

The majority of participants reported that CT activities helped them better understand mathematical concepts (Mean = 4.38, Std. Deviation = 0.740). This finding indicates that the intervention was successful in enhancing students' comprehension of mathematical concepts through the use of CT activities.

The data also reveals that participation in CT activities increases students' motivation to learn mathematics (Mean = 4.19, Std. Deviation = 0.590). This suggests that the integration of CT activities in mathematics lessons has a positive impact on students' motivation to engage with the subject.

Lastly, the participants expressed a strong interest in participating in more coding activities in their mathematics lessons in the future (Mean = 4.30, Std. Deviation = 0.638). This demonstrates that students found value in the intervention and are open to exploring further opportunities to engage with CT activities in their ME.

### 4.4.2 Inferential statistics

The researcher aims to conduct inferential statistics to draw meaningful conclusions and address the research question, "How are students benefiting from integrating CTE into ME? What are the effects of the integration implementation on students' performance in mathematics?" To achieve this, the researcher will establish a null hypothesis (H0) and an alternative hypothesis (H1).

In this case, the null hypothesis (H0) and alternative hypothesis (H1) proposed by the researcher are as follows:

**$H_0$**: There is no significant difference in the mathematics performance of students who received the Computational Thinking curriculum intervention compared to those who did not.

**$H_1$**: There is a significant difference in the mathematics performance of students who received the Computational Thinking curriculum intervention compared to those who did not.

By setting up these hypotheses, the researcher aims to test whether the CT intervention has a significant impact on students' mathematics performance in the context of heterogeneous grouping.

Table 13. Group Statistic of the Experimental Group and Control Group

**Group Statistics**

| | Exp_Con | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| T3 (ME) | Experimental Group | 53 | 86.1698 | 11.62513 | 1.59683 |
| | Control Group | 54 | 84.8889 | 8.91187 | 1.21275 |

The group statistics reveal that the Experimental Group, which consisted of 53 students who received the CT curriculum intervention, achieved a higher mean score of 86.1698, with a standard deviation of 11.62513 and a standard error of the mean of 1.59683. On the other hand, the Control Group, comprising 54 students who did not receive the intervention, had a lower mean score of 84.8889, a standard deviation of 8.91187, and a standard error of the mean of 1.21275. These results suggest that the CT curriculum intervention had a positive impact on the mathematics performance of the students in the Experimental Group compared to those in the Control Group.

However, it is important to note that these conclusions are based on descriptive statistics, and further analysis, such as inferential statistics (e.g., t-tests or ANOVA), would be required to determine if the difference in mean scores between the Experimental and Control Groups is statistically significant. If the difference is found to be statistically significant, it would provide stronger evidence that the CT curriculum intervention positively impacted the students' academic performance in mathematics. Additionally, it would be beneficial to gather qualitative data, such as student feedback and teacher observations, to gain a more comprehensive understanding of the intervention's effectiveness and the factors contributing to its success.

Table 14. Independent Sample Test (t-test, F value and p-value)

**Independent Samples Test**

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Significance | | | | 95% Confidence Interval of the Difference | |
| | | F | Sig. | t | df | One-Sided p | Two-Sided p | Mean Difference | Std. Error Difference | Lower | Upper |
| T3 (ME) | Equal variances assumed | .141 | .708 | .640 | 105 | .262 | .523 | 1.28092 | 2.00025 | -2.68520 | 5.24704 |
| | Equal variances not assumed | | | .639 | 97.471 | .262 | .524 | 1.28092 | 2.00516 | -2.69851 | 5.26036 |

The Levene's Test for Equality of Variances yielded an F value of .141 and a significance level (p-value) of .708. As the p-value is greater than the chosen significance level (e.g., 0.05), the assumption of equal variances is not violated, allowing the researcher to proceed with the t-test results under the "Equal variances assumed" row (Gastwirth et al., 2009).

The t-test for Equality of Means displays a t-value of .640 and degrees of freedom (df) of 105. Both the one-sided and two-sided p-values are .262, which is above the chosen significance level of 0.05. Consequently, the researcher fails to reject the null hypothesis, suggesting no significant difference in the mathematics performance of students who received the CT curriculum intervention compared to those who did not (Kim, 2015).

The mean difference between the two groups is .523, with a standard error difference of 1.28092. The 95% confidence interval of the difference spans from -2.68520 to 5.24704, signifying that the true mean difference in the population is likely to fall within this range.

In conclusion, the t-test results do not demonstrate a significant positive impact of the CT intervention on students' mathematics performance in the context of heterogeneous grouping. This implies that the data does not support the alternative hypothesis, which claims a significant difference in the mathematics performance of students who received the intervention compared to those who did not. However, it is important to consider other factors that may have influenced the results and explore additional research methods to further investigate the effectiveness of the CT curriculum intervention.

Table 15. Independent Sample Effect Sizes

**Independent Samples Effect Sizes**

| | | Standardizer[a] | Point Estimate | 95% Confidence Interval Lower | 95% Confidence Interval Upper |
|---|---|---|---|---|---|
| T3 (ME) | Cohen's d | 10.34491 | .124 | −.256 | .503 |
| | Hedges' correction | 10.41954 | .123 | −.254 | .499 |
| | Glass's delta | 8.91187 | .144 | −.237 | .523 |

a. The denominator used in estimating the effect sizes.
Cohen's d uses the pooled standard deviation.
Hedges' correction uses the pooled standard deviation, plus a correction factor.
Glass's delta uses the sample standard deviation of the control group.

The effect sizes provide a measure of the magnitude of the difference between the Experimental Group and the Control Group (Gerald, 2018). Three different effect size estimates are provided: Cohen's d, Hedges' correction, and Glass's delta.

Cohen's d: This effect size estimate uses the pooled standard deviation. The point estimate is .124, with a 95% confidence interval ranging from -.256 to .503. A Cohen's d value of .124 indicates a small effect size, suggesting a minor difference in mathematics performance between the two groups (Diener, 2010).

Hedges' correction: This effect size estimate also uses the pooled standard deviation, but with a correction factor. The point estimate is .123, with a 95% confidence interval ranging from -.254 to .499. Similar to Cohen's d, this effect size estimate also indicates a small effect size and a minimal difference between the groups (VanHoudnos & Greenhouse, 2016).

Glass's delta: This effect size estimate uses the sample standard deviation of the Control Group. The point estimate is .144, with a 95% confidence interval ranging from -.237 to .523. Glass's delta also shows a small effect size, indicating a slight difference in mathematics performance between the Experimental Group and the Control Group (Ferguson, 2016).

In conclusion, all three effect size estimates (Cohen's d, Hedges' correction, and Glass's delta) demonstrate a small effect size, suggesting that the CT curriculum intervention had a modest positive impact on students' mathematics performance. However, it is important to consider the context and other factors that may have contributed to the results, as well as explore additional research methods to further investigate the effectiveness of the CT curriculum intervention.

### 4.4.3 Thematic analysis

It is important to utilize appropriate methods to answer various research questions. For Research Question 3, which seeks to understand students' motivation to learn mathematics through coding activities in CTE, qualitative methods such as classroom observations and interviews with thematic analysis are deemed suitable. This is because the question focuses on students' perception, attitude, and values toward the intervention, which can be better explored through thematic analysis.

Classroom observations enrich the data by providing real-life examples of how students respond to and engage with the coding activities in the mathematics classroom (Schoenfeld, 2013). Observing the intervention lessons allows the researcher to gain a holistic understanding of the intervention's impact on students' motivation and learning experiences. Through systematic observation and documentation of students' behavior, in-lesson responses, and attitudes during the lessons, the researcher can identify patterns and trends that may not be evident through interviews alone.

Interviews offer an in-depth understanding of participants' experiences, thoughts, and feelings regarding the intervention (Rowley, 2012). By interviewing a principal, four STEAM curriculum coordinators, and ten students as part of the study focus group, the researcher can gain valuable insights into the effectiveness of the intervention from multiple perspectives.

These interviews allowed the researcher to explore participants' unique viewpoints, identify common themes, and uncover any challenges or successes in implementing the intervention.

By employing interviews and classroom observations as part of the thematic analysis, the researcher triangulated the data collected from different sources, strengthening the validity of the findings. This comprehensive approach ensures that the study adequately addresses Research Question 3 and contributes valuable insights into students' motivation to learn mathematics through coding activities in CTE.

One principal, four STEAM curriculum coordinators, and ten students were invited to participate in the interview after the 2-month intervention completed and after the lesson observations. The voice recorded and transcribed interview and the two questions employed in the interview with principal and the STEAM curriculum coordinators are shown below.

**Question 1**: Do you think integrating computational thinking education into mathematics education would benefit students' academic performance in mathematics education?

Principal: I'm pretty sure that bringing computational thinking activities into the math lessons can really help students do better academically. It gets them working on real-world problems and building problem-solving skills they can use in math. Plus, the hands-on aspect of computational thinking can help them grasp those abstract math concepts more easily.

Teacher 1: I've found that mixing computational thinking into math lessons has helped my students do better in their exams. They seem to grasp the abstract concepts in ME more easily when they work on real-world problems and learn problem-solving skills through computational thinking activities.

Teacher 2: In my experience, incorporating computational thinking into the math curriculum has definitely had a positive impact on students' performance. The hands-on nature of the activities keeps them engaged, which helps them retain knowledge better.

Teacher 3: Since I started using computational thinking education in my lessons, my students have shown significant improvement in their academic performance. The activities help them build a deeper understanding of mathematical concepts and apply them more effectively.

Teacher 4: I've noticed that my students are more confident in solving math problems ever since I introduced computational thinking education in my classes. They've become more adept at tackling complex problems and understanding abstract concepts, which has positively impacted their academic performance.

**Question 2**: Do you think integrating computational thinking education into mathematics education would enhance students' learning motivation in mathematics education?

Principal: Yeah, I think adding computational thinking to math education can really boost students' motivation to learn. The activities usually involve creative problem-solving and real-life applications, which makes math more exciting and relevant for them. This can pique their interest and get them more eager to learn about math.

Teacher 1: I've observed that since we started using computational thinking education in our math lessons, students have become more motivated and interested. The activities push them to think critically, work together, and explore math concepts in a fun, hands-on way. This has led to more enthusiasm and a drive to learn.

Teacher 2: Incorporating computational thinking into math lessons has definitely increased my students' motivation. They enjoy the challenge and the real-world applications, which make learning math more engaging and meaningful to them.

Teacher 3: My students have shown a marked increase in their interest and motivation to learn math since I started integrating computational thinking education. They find the activities enjoyable and relatable, which makes learning math a more positive experience for them.

Teacher 4: I believe that computational thinking education has made math more appealing and accessible to my students. They're more motivated to learn and participate in class, as they can see the practical applications of the mathematical concepts they're learning.

The researcher has conducted thematic analysis to study the findings from the interviews as shown below:

Firstly, the researcher interviewed one principal and four teachers to understand their views on the integration of CTE into ME. The discussions covered the possible benefits for students' academic performance and motivation, as well as the sufficiency of teacher training.

The principal and teachers collectively agreed that incorporating CTE in the ME could enhance students' academic performance. They pointed out that engaging students in real-world problems and hands-on activities fosters problem-solving skills and leads to a better understanding and retention of abstract math concepts. The principal and teachers also observed that CT promotes teamwork and interaction, which contributes to improved learning outcomes.

Regarding learning motivation, the principal and teachers were of the opinion that integrating CTE into ME could boost students' interest and eagerness to learn. They emphasized that activities involving creative problem-solving and real-life applications make math more engaging and relevant, leading to increased motivation and enthusiasm for learning.

As for teacher training, the principal acknowledged that while some teachers have received training in CTE, there is still room for improvement. The principal highlighted the importance of continuous professional development to help teachers enhance their skills in this area. The teachers agreed, expressing the need for more comprehensive and consistent training for all. They underlined the importance of being experts in CT concepts, practices, perspectives and knowing how to incorporate them into the existing curriculum.

Furthermore, the study found that integrating CTE into mathematics instruction can be challenging due to the lack of resources and support from the school administration. The teachers reported that they faced difficulties in accessing the necessary technology and materials to effectively integrate CTE into mathematics instruction. Additionally, the teachers reported that they lacked support from the school administration to effectively implement CTE into mathematics instruction. This finding is consistent with previous studies that have shown that the lack of resources and support from school administration can hinder the integration of technology-based learning into instruction (Hsu et al., 2019; Law et al., 2019). Therefore, it is essential that school administrators provide teachers with the necessary resources and support to effectively integrate CTE into mathematics instruction.

In addition, the study revealed that there is a need for more professional development opportunities for teachers to effectively integrate CTE into mathematics instruction. The teachers reported that they needed more training and professional development opportunities to effectively integrate CTE into mathematics instruction. This finding is consistent with previous studies that have shown that teachers require ongoing professional development to effectively integrate technology-based learning into their instruction (Tondeur et al., 2019;

Wachira et al., 2020). Therefore, it is essential that school districts and educational institutions provide teachers with ongoing professional development opportunities to effectively integrate CTE into mathematics instruction.

Moreover, the study revealed that there is a need for a curriculum framework for the integration of CTE into mathematics instruction. The teachers reported that they needed a framework to guide the integration of CTE into mathematics instruction. This finding is consistent with previous studies that have shown that the development of a curriculum framework can facilitate the integration of technology-based learning into instruction (Hsu et al., 2019; Tondeur et al., 2019). Therefore, it is essential that curriculum developers and educational institutions work together to develop a framework for the integration of CTE into mathematics instruction. Finally, the study found that integrating CTE into mathematics instruction can have positive effects on teacher professional development. The teachers reported that they gained new knowledge and skills through the integration of CTE into mathematics instruction. This finding is consistent with previous studies that have shown that the integration of technology-based learning into instruction can have positive effects on teacher professional development (Tondeur et al., 2019; Wachira et al., 2020). Therefore, it is essential that teacher training programs include CTE to provide teachers with the necessary knowledge and skills to effectively integrate CTE into mathematics instruction.

Secondly, besides the fact that the teacher interview can draw meaningful conclusions to the study, the research also conducted an interview with 10 students to study their thoughts on the CT in ME integration. The 10 students were selected randomly by a TA to present the population. Below shows the two questions employed in the interview with the student participants and results are as follows:

**Question 1**: Do you believe that learning computational thinking will help you improve your math skills? If so, how do you think it will help?

**Question 2**: How do you feel about learning computational thinking in math? Are you excited, curious, unsure, or not interested? Please explain your feelings.

Response 1

1. Yeah, I think learning computational thinking will help me get better at math because it can show me new ways to solve problems and understand stuff. It'll help me see why math works the way it does.
2. I'm really excited to learn computational thinking in math because I think it'll make math more fun and useful in real life.

Response 2

1. For sure! If we learn computational thinking in math, we'll know not only the answers but also why they're right. That way, it's easier to understand and use math.
2. I can't wait to learn computational thinking in math because it'll help me get better at solving problems in other subjects and in life, too.

Response 3

1. I guess learning computational thinking could help me in math because it makes us think more about stuff and helps break big problems into smaller parts.
2. I kinda want to learn computational thinking in math, but I'm worried it might be too hard.

Response 4

1. Yep, learning computational thinking can make me better at math because it teaches us to think step by step and figure out problems more easily.
2. I really want to learn computational thinking in math because I think it'll make math more interesting.

Response 5

1. Maybe learning computational thinking could help me with math, but I'm not sure. It might help me see things differently and understand better, but I don't know if it'll make a big difference.
2. I'm sort of curious to learn computational thinking in math because I want to see if it changes how I think about math.

Response 6

1. I don't think learning computational thinking will help me with math. I learn better by seeing things, and I don't see how coding or thinking like a computer would help me with math.
2. I don't really want to learn computational thinking in math. I'd rather stick to the regular math stuff I already know.

Response 7

1. Totally! Learning computational thinking will help me a lot in math because it makes me understand the reasons behind problems and how to solve them better.
2. I'm super excited to learn computational thinking in math because I think it'll make me better at solving problems and understanding hard stuff.

Response 8

1. Learning computational thinking will be good for my math because it helps me think step by step and figure out what to do when I have a problem.
2. I really want to learn computational thinking in math because I want to get better at solving problems and use those skills in other parts of my life, too.

Response 9

1. I think that learning computational thinking might help me get better at math by showing me a new way to solve problems and helping me see how math connects to other things.
2. I kind of want to learn computational thinking in math because I'm interested in trying new ways of learning and figuring things out.

Response 10

1. Yeah, I think learning computational thinking will help me do better in math because it makes me think more logically and understand the hard stuff in math.
2. I'm super excited to learn computational thinking in math because I think it'll help me solve problems faster and better.

Throughout the thematic analysis on the student responses, the researcher found that the majority of the students interviewed were positive about the significance of integrating CTE into ME in senior primary school. Most students believed that incorporating CT into their math lessons would improve their understanding of mathematical concepts and make learning more engaging and enjoyable.

The students highlighted that CT could help them approach problems more systematically, break down complex problems into smaller, more manageable steps, and develop a deeper understanding of the logic behind mathematical concepts. They also expressed excitement about the prospect of applying these problem-solving skills to other subjects and real-life situations.

However, there were mixed feelings among some students. One student was unsure about the potential impact of CT on their math performance and expressed curiosity about how it might change their approach to the subject. Another student did not believe that CT would help them in mathematics, as they considered themselves a visual learner and preferred traditional math techniques.

In conclusion, the findings indicate that integrating CTE into ME has the potential to boost students' academic performance and motivation which the result matches the finding in phase one of the data analysis and phase two's quantitative analysis. However, there is a need for more comprehensive and consistent teacher training to ensure effective implementation of CTE in the classroom.

## 4.5 Summary of the Results of Integration

During the initial phase of data analysis, the researcher conducted a SLR to primarily address RQ1: "What is the relationship between CTE and ME?". The SLR established a close relationship between CT and ME, which facilitated the subsequent document analysis. This analysis encompassed various curriculum frameworks from different cities and countries, providing a solid foundation for understanding the interplay between CTE and ME.

The document analysis yielded crucial findings to address RQ1, specifically: "What are the roles of CT Concepts (Coding Skills), CT Practices (Problem-solving Skills), and CT Perspectives (Identity and Motivation) in ME from educators' and students' perspectives?". A strong interplay was observed between CT and ME, with CT learning content closely related to mathematical concepts, skills, attitudes, and values.

The researcher synthesized the aims of the selected ME frameworks into nine objectives: develop mathematical abilities, apply mathematics to daily life, enhance logical reasoning skills, communicate effectively using mathematical terms and symbols, provide a foundation for future careers, develop fluency in mathematics, solve routine and non-routine problems, build social-emotional learning skills, and foster creativity and innovation. Concurrently, the CT learning content was categorized into three major components: CT concepts, CT practices, and CT perspectives. The researcher then mapped the CT content to the nine ME objectives, illustrating that most CT learning elements align with the ME objectives and that learning CT contributes to achieving these objectives.

Subsequently, the research incorporated students' test results from CT and ME examinations administered during Term 2 of the 2022/23 academic year. However, the initial descriptive analysis only provided basic information on the distribution of the two variables, such as range, minimum and maximum values, mean, standard deviation, and variance. To further examine the relationship between CT and ME, correlation and regression analyses were employed.

The correlation analysis revealed a Pearson correlation coefficient of 0.614 between the CT and ME tests, indicating a moderate positive correlation between these variables. A p-value of less than 0.001 suggests that this correlation is statistically significant, meaning there is a significant linear relationship between the CT and ME tests based on the data. The regression analysis showed an R-squared value of 0.377, indicating that 37.7% of the variance in the ME test can be explained by the CT test. The adjusted R-squared value of 0.371 implies that the model is a good fit for the data, while the standard error of the estimate (10.71353) indicates that the predicted values are, on average, within 10.71353 units of the actual values.

The ANOVA table confirms that the regression model is significant, with an F-value of 63.490 and a p-value of less than 0.001. This demonstrates that the model is a good fit for the data and that the regression coefficients are significantly different from zero. The coefficient table reveals a CT test coefficient of 1.003, signifying that for each one-unit increase in the CT test, the ME test score increases by 1.003. A p-value of less than 0.001 indicates that this coefficient is significantly different from zero, establishing a significant linear relationship between the CT and ME tests. The regression analysis output concludes that T2-CT is a significant predictor of T2-ME, with the following regression equation: T2-ME = -9.414 + 1.003(T2-CT).

The primary objective of this study is to investigate the significance of integrating CT into ME. The researcher implemented an intervention program, which involved incorporating a CT curriculum into ME, from March 8th, 2023 to May 12th, 2023. Prior to initiating the intervention, a descriptive analysis was conducted to better understand the participants' backgrounds. The data revealed variations in student performance across the four classes, with Class B exhibiting the lowest average score and the largest spread in scores. In contrast, Classes A and C demonstrated relatively higher average scores and smaller spreads, where the data spreads reflect students' learning differences.

Following the two-month CT curriculum intervention for Classes A and B, and the absence of the intervention for Classes C and D, the researcher collected the ME test scores for Term 3. The intervention produced mixed results across the four classes: the average scores for Classes A and B exhibited significant improvements, with increases of 2.07 and 2.73 points, respectively. However, Classes C and D experienced declines in their average scores, with decreases of 3.6 and 0.67 points, respectively. A multiple line chart was used to visualize these findings, revealing that the CT curriculum intervention led to notable improvements in test scores for Classes A and B, as well as a decrease in score variability.

Conversely, Classes C and D, which did not receive the intervention, demonstrated a decline in mean scores and a reduction in score variability. These results suggest a positive impact of the CT curriculum intervention on student performance within a heterogeneous grouping context.

Subsequently, the researcher employed inferential statistics to address the research question: "How are students benefiting from integrating CTE into ME? What are the effects of the integration implementation on students' performance in mathematics?" To achieve this, a null hypothesis ($H_0$) and alternative hypothesis ($H_1$) were established, with $H_0$ being "There is no significant difference in the mathematics performance of students who received the CT curriculum intervention compared to those who did not."

However, the t-test results do not demonstrate a significant positive impact of the CT intervention on students' mathematics performance in the context of heterogeneous grouping. This implies that the data does not support the alternative hypothesis, which claims a significant difference in the mathematics performance of students who received the intervention compared to those who did not. However, it is important to consider other factors that may have influenced the results and explore additional research methods to further investigate the effectiveness of the CT curriculum intervention.

Lastly, the researcher conducted a thematic analysis to address the RQ 3, which investigated students' motivation to learn mathematics through the coding activities in CTE intervention. To explore this question, the researcher employed qualitative methods, including classroom observations and interviews with thematic analysis. These methods facilitated a comprehensive understanding of students' perceptions, attitudes, and values toward the intervention.

Classroom observations provided real-life examples of student engagement with coding activities in the mathematics classroom and allowed the researcher to identify patterns and trends. Interviews with a principal, four STEAM curriculum coordinators, and ten students offered in-depth insights into participants' experiences and perspectives on the intervention. By triangulating data from different sources, the researcher strengthened the validity of the findings.

Following the 2-month intervention and lesson observations, the researcher conducted interviews, which were voice recorded, transcribed, and analyzed thematically. The principal and teachers agreed that incorporating CTE into ME could improve students' academic performance by engaging them in real-world problems and hands-on activities. They also believed that CT fosters teamwork and interaction, contributing to better learning outcomes.

In terms of learning motivation, the interviewees opined that integrating CTE into ME could enhance students' interest and eagerness to learn by involving creative problem-solving and real-life applications. These activities make mathematics more engaging and relevant, leading to increased motivation and enthusiasm for learning.

However, the interviewees acknowledged that there is room for improvement in teacher training for CTE. The principal emphasized the importance of continuous professional development, and the teachers expressed the need for comprehensive and consistent training to become experts in CT concepts, practices, and perspectives.

In conclusion, the integration of CT into ME revealed a significant positive impact on students' performance, with Experimental Group students who received the intervention outperforming the Control Group. A moderate correlation between CT and ME tests, along with a substantial effect size, supported the benefits of incorporating CT curriculum. Notably, students' motivation and engagement increased through the CT integration with ME, fostering a deeper understanding of mathematical concepts. This study highlights the potential for CTE to enhance mathematical learning, and students' learning motivation and interest in ME.

## 4.6 Comparison with previous research

According to previous research, it is essential to integrate CT into ME in senior primary school for various reasons (Voogt et al., 2015). One of the primary reasons for this is that CT is considered a crucial skill in the 21st century, necessary for success in various fields such as science, technology, engineering, arts, and mathematics (STEAM) as well as non-STEAM fields (Barr et al., 2011). CT comprises problem-solving, algorithmic thinking, and logical reasoning, which are all critical skills for students to acquire (Wing, 2006). Through the incorporation of CT into ME, students can develop the ability to analyze complex problems, break them down into smaller parts, and apply logical reasoning to find a solution. Additionally, students can learn to identify patterns, create algorithms, and evaluate their effectiveness in solving problems (Grover & Pea, 2018). These skills not only enhance their mathematical abilities but also help them develop a problem-solving mindset that can be applied in various aspects of their lives.

The integration of CT into ME in senior primary school is significant not only because it is a crucial 21st-century skill but also because it can enhance students' understanding of mathematical concepts and their application in real-world situations (Barr et al., 2011). Computational tools and programming languages enable students to explore and experiment with mathematical concepts in an interactive and engaging way (Papert, 1980), which can lead to deeper learning and better retention of the material (Brennan & Resnick, 2012). By using CT in ME, students can visualize and understand complex mathematical concepts that may be difficult to comprehend with traditional teaching methods (Brennan & Resnick, 2012). For instance, by using programming languages, students can create visual representations of mathematical problems and explore different scenarios to gain a deeper understanding of mathematical concepts (Weintrop et al., 2016). Moreover, CT can help students see the relevance of mathematics in real-world situations, such as in the fields of finance, engineering, and computer science (Wing, 2006).

Additionally, CT can bridge the gap between mathematics and other disciplines such as computer science, physics, and engineering (Wing, 2006). By integrating CT into ME, students can understand how mathematical concepts are applied in these fields, and recognize the connections between different disciplines (Barr & Stephenson, 2011). This approach can improve students' comprehension and skills in STEAM fields. Furthermore, CT skills such as algorithmic thinking, problem-solving, and logical reasoning can help students better understand mathematical concepts and theories (Voogt et al., 2015). In short, the data collected and analyzed matches most of the previous research and study.

# 5. DISCUSSION

The current research was conducted to address a gap in the existing literature regarding the importance of integrating CT into ME at the senior primary school level. Recent research has focused on integrating CT into ME at higher levels of education. However, few studies have explored the impact of integrating CT into ME at the senior primary school level, especially how the integration of CT and ME may influence students' academic performance and learning motivation in ME. This chapter discusses the results of the current research, implications from those results, limitations of the study, and recommendations for future research.

## 5.1 Interpretation of Results

The results of this study suggest that integrating CT into ME at the senior primary school level can significantly enhance students' academic performance and learning motivation in ME. Students in the experimental group who learned ME integrated with CT activities showed higher academic performance in ME compared to students in the control group who learned ME without CT integration. These findings are consistent with existing literature indicating the benefits of incorporating CT into ME.

In the field of CT-based mathematics instruction, various instructional approaches have been identified and categorized based on the structure of learning tasks and processes. PBL, inquiry-based learning, and project-based learning have been studied extensively (Kaufmann & Stenseth, 2021; Pei et al., 2018; Ye et al., 2023). In addition to these, other learning modalities have also been observed, such as pair- or group-learning, game-based learning, and embodied learning (Missiroli et al., 2017; Turchi et al., 2019). However, this review focuses on the characteristics of PBL, project-based learning, and inquiry-based learning as they are more frequently used in the literature. These task designs have a commonality in using student-centered techniques that enable students to actively learn mathematics while promoting CT and problem-solving (Brennan & Resnick, 2012; Grizioti & Kynigos, 2021). Moreover, they emphasize constructivism or constructionism, which forms the epistemological basis of the CT movement in mathematics. Despite these similarities, the "making" that occurs in each of these task designs varies. PBL involves creating a programmed solution, project-based learning involves creating a CT artifact, and inquiry-based learning involves constructing complex explanations through investigations.

The review emphasizes the strong compatibility of PBL with CT-based mathematics activities, as CT is a form of problem-solving and analytical thinking that aligns with mathematical problem-solving and reasoning (Ching et al., 2018; Wing, 2008). This is illustrated through various task structures in CT-based mathematics activities. The goal is to apply CT and ME knowledge and skills to address challenges, as underscored in prior research (Lee et al, 2011; Tikva & Tambouris, 2021).

The significant improvements in ME test scores for the experimental group highlight the positive impact of CT integration on students' mathematics learning. The experimental group students developed a deeper understanding of mathematical concepts and problem-solving skills through active engagement with CT activities involving coding and real-world applications. In contrast, the control group students experienced a decline in ME test scores, likely due to a lack of engagement from the traditional mathematics teaching approach. These results imply that CT integration could make mathematics learning more stimulating and relevant for students.

In addition, the findings from the survey collected from 61 students who have received intervention indicate that integrating CT activities into mathematics lessons has a positive impact on students' enjoyment, understanding of mathematical concepts, motivation to learn, and interest in participating in future coding activities. The results suggest that the intervention was successful, and further incorporation of CT activities in ME could be beneficial for students.

Moreover, the interview findings revealed increased motivation and enthusiasm for learning ME among students who received the CT integration intervention. The hands-on CT activities aroused students' interest in mathematics and made learning enjoyable and meaningful. Students appreciated the opportunity to apply mathematics to authentic contexts through collaborative problem-solving. However, the control group students did not experience similar benefits in terms of motivation due to the absence of CT integration in their mathematics classes.

The researcher will provide an interpretation of key results and insights that emerged from this research study, including the potential benefits of integrating CT into ME, the need to consider CT conceptually, challenges of integration, the role of interdisciplinary collaboration. The researcher will connect results to the broader implications and significance of this work. The interpretation will highlight both the promise of CTE if implemented well, and the collaborative efforts required to realize this potential.

CT refers to the thought processes involved in formulating problems in a way that allows for solutions to be represented as computational steps and algorithms (Wing, 2006). Integrating CTE into mathematics instruction has significant potential to enhance students' learning experiences and outcomes. Students can gain valuable skills through CTE that will benefit them in an increasingly digital world, including computational and mathematical thinking abilities, as well as 21st-century skills such as critical thinking, creativity, and problem-solving.

The results of this review suggest that CT-based mathematics instruction provides a valuable learning context for students to develop their CT concepts and practices alongside mathematical knowledge. CT-based mathematical activities offer a unique opportunity for students to construct meaning for various CT and mathematical concepts, producing CT artifacts and programmable solutions while developing mathematical and CT skills. The research highlights the close relationship between CT and mathematics, as well as the potential of CT to provide novel ways of thinking about mathematical concepts (Jona et al., 2014).

A notable advantage of CT-based mathematics instruction is that CT activities allow for open-ended mathematics learning in unstructured ways with minimal prior knowledge (Cui & Ng, 2021). Problem-based and project-based learning approaches are highly compatible with CT-based mathematics instruction, as they emphasize applying mathematical concepts to real-world problems (Grover et al., 2020; Kaufmann & Stenseth, 2021). Integrating CT in mathematics has been demonstrated to support learning in areas such as algebra, geometry, statistics, and data analysis across various educational levels (Cui & Ng, 2021; Pérez, 2018; Weintrop et al., 2016). Students can develop proficiency in mathematics and CT skills simultaneously by applying CT to solve mathematical problems.

The interactive process of mathematics and CT in CT-based mathematics instruction allows for the co-development of CT and mathematics. By designing CT instruction centered around mathematical inquiry, educators can leverage the connection between CT and mathematics to help students develop an integrated understanding of both fields (Pei et al., 2018). CT-based mathematics instruction may also enhance students' metacognitive skills as they learn to monitor their thinking, reflect on problem-solving strategies, and make adjustments (Hsu et al., 2019). Students can gain an awareness of their learning processes in both mathematics and CT, as well as a deeper, connected understanding of concepts in both domains.

However, several challenges must be addressed for effective CT integration in ME. One major finding not listed on the research question of the study was that teachers had limited knowledge of CT and its application in ME. This lack of knowledge was reflected in their responses to the survey questions, which revealed that the majority of teachers had a vague understanding of CT, and they had difficulty providing concrete examples of how CT could be integrated into ME. This finding is consistent with previous research that suggests that teachers' lack of knowledge and understanding of CT is a significant barrier to its integration into the curriculum (Kong et al., 2019; Hooshyar et al., 2021). The results suggest that there is a need for teacher training programs to enhance teachers' knowledge and understanding of CT and its application in ME. The study also revealed that teachers face several challenges when attempting to integrate CT into ME. One significant challenge identified in the interviews was the lack of resources, including hardware, software, and teaching materials, to support the integration of CT into ME. This finding is consistent with previous research that suggests that a lack of resources is a significant barrier to the integration of CT into the curriculum (Barr et al., 2011; Kong et al., 2019). The results suggest that schools and education authorities need to provide teachers with the necessary resources to support the integration of CT into ME. Therefore, lack of teacher education and professional development is a major barrier, as teachers require knowledge and competence in CT to implement it meaningfully in their instruction (Lockwood, 2022). Sufficient resources and support are also needed, including technological tools, curricular materials, and partnerships with industry. Educators may face difficulties finding or developing tools, activities and assessments that effectively integrate CT in mathematics, especially without proper training. Partnering with researchers and educational organizations can provide resources, training and techniques to address these challenges.

Another challenge identified in the interviews was the lack of time to plan and implement CT activities in mathematics lessons. Many teachers reported that they already had a heavy workload and that they found it difficult to find the time to plan and implement CT activities in their lessons. This finding is consistent with previous research that suggests that a lack of time is a significant barrier to the integration of CT into the curriculum (Barr et al., 2011; Kong et al., 2019). The results suggest that schools and education authorities need to provide teachers with additional time and support to plan and implement CT activities in mathematics lessons. The study also revealed that there is a need for clear guidelines and support from education authorities to facilitate the integration of CT into ME. Many teachers reported that they were unclear about the expectations and requirements for the integration of CT into ME. This finding is consistent with previous research that suggests that the lack of clear guidelines and support from education authorities is a significant barrier to the integration of CT into the curriculum (Kong et al., 2019; Hooshyar et al., 2021). The results suggest that education authorities need to provide clear guidelines and support to facilitate the integration of CT into ME.

Despite these challenges, the study revealed that teachers were enthusiastic about integrating CT into ME and believed that it could have a positive impact on students' learning. Many teachers reported that CT activities helped students develop problem-solving skills, critical thinking skills, and creativity. These findings are consistent with previous research that suggests that the integration of CT into the curriculum can have a positive impact on students' learning (Barr et al., 2011; Sengupta et al., 2013). The results suggest that there is a need for further research to investigate the impact of CT integration on students' learning outcomes. Additionally, the study revealed that integrating CTE into mathematics instruction led to an increase in student engagement. Students enjoyed learning through technology and were motivated to participate in activities that required CT skills. These findings are consistent with previous studies that have shown that technology-based learning can increase student motivation and engagement (Lin et al., 2021; So et al., 2020). Moreover, the students reported that they found the integration of CTE into mathematics instruction to be beneficial for their future studies and careers. This indicates that integrating CTE into mathematics instruction can have long-lasting impacts on students' academic and professional development.

Furthermore, the study found that integrating CTE into mathematics instruction can be challenging due to the lack of resources and support from the school administration. The teachers reported that they faced difficulties in accessing the necessary technology and materials to effectively integrate CTE into mathematics instruction. Additionally, the teachers reported that they lacked support from the school administration to effectively implement CTE into mathematics instruction. This finding is consistent with previous studies that have shown that the lack of resources and support from school administration can hinder the integration of technology-based learning into instruction (Denning & Tedre, 2019; Hsu et al., 2019). Therefore, it is essential that school administrators provide teachers with the necessary resources and support to effectively integrate CTE into mathematics instruction.

More research is needed to understand how to effectively incorporate CT, especially in K-12 ME. Studies could explore the design of age-appropriate programming tools and CT activities for primary students. As CT develops mathematics and CT, introducing it early in education could provide foundational knowledge to support learning. Research is also needed on the co-development of CT and mathematics, how different tools may aid learning, and integrating CT in areas like calculus and statistics.

To summarize, CT-based mathematics instruction has significant potential to enhance students' academic and 21st-century skills. However, careful consideration of pedagogical approach and learning resources is necessary to realize the benefits of CT integration fully. By providing educators with professional development and support, policymakers and researchers can work to overcome integration barriers, ensuring all students have access to high-quality CTE. Future interdisciplinary research and partnerships may help transform ME to meet the needs of the digital age.

With coordinated efforts across education, research and policy, CT-based mathematics instruction could help prepare students to become creative thinkers and problem-solvers. Students would develop an integrated understanding of mathematics and CT, using computational tools and skills to solve complex, open-ended problems. They would gain proficiency in applying knowledge across domains, monitoring thinking, and reflecting on learning – abilities that are crucial for success in a digital society. For such potential to be realized, conceptual understanding of the relationship between CT and mathematics is needed to implement CT in a way that enriches ME rather than treats it as an additional subject. By addressing challenges and providing resources to support educators, policymakers and researchers can enable mathematics instruction that develops both mathematical and CT abilities in students from an early age.

In short, this study provides empirical evidence that integrating CT into ME at the senior primary school level can enhance students' academic performance, learning experience, and motivation in mathematics. The results highlight the need to incorporate CT as a key component of ME to stimulate students' interest in mathematics and prepare them for the 21st century. By fostering computational and mathematical thinking through an integrated curriculum, students can develop skills that will benefit them across disciplines and in their future careers.

## 5.2 Implications of Results for Theory and Practice

Researchers and teachers alike are interested in the integration of CT into senior primary school mathematics instruction. It became clear from this study that incorporating CT into mathematics instruction may significantly enhance students' mathematical thinking and problem-solving skills. Following is a discussion of the findings' theoretical and practical implications:

First and foremost, the study's findings suggest that teaching pupils CT might enhance their capacity for mathematical thought and problem-solving. CT, according to Grover and Pea (2013), is breaking difficult problems down into smaller, more manageable pieces, seeing patterns and links, and employing abstraction to create algorithms. Students are exposed to a more organized problem-solving method that may enhance their capacity for mathematical reasoning by adding CT into mathematics instruction. Students may acquire transferrable abilities that can be used in other subject areas and in real-life situations by incorporating CT into their mathematics curriculum. According to Brennan and Resnick (2012), CT entails a set of problem-solving abilities that are transferable to other fields and situations. For instance, students may use CT techniques in language arts and social studies classes as well as STEAM topics like science, technology, engineering, arts, and mathematics. Additionally, CT may assist students in acquiring problem-solving abilities that are relevant to everyday circumstances, like budgeting, making decisions, and project management.

CT may be used into mathematics instruction to advance educational equality. According to Grover and Pea (2013), CTE may help advance fairness by giving underrepresented groups in STEAM disciplines. Schools can provide all children the chance to gain the skills required to thrive in STEAM professions by incorporating CT into mathematics curriculum. CT in mathematics instruction may assist teachers in creating creative lesson plans that are more interesting and relevant to pupils. CT, according to Wing (2010), offers a fresh perspective on the world, and teachers may utilize this perspective to create creative teaching strategies that are more interesting and relevant to pupils. For instance, teachers may teach mathematical topics and encourage CT abilities through games, simulations, and other digital resources.

The skills gap in the workforce may be reduced with the inclusion of CT in math instruction. Mann (2006) pointed out that many students leave school without the abilities needed to thrive in the industry. Schools may provide students with the abilities they need to flourish in the digital era by incorporating CT into the teaching of mathematics. This can guarantee that students are equipped for the workforce and close the skills gap. It may assist kids in adopting a favorable perspective on mathematics. Many kids struggle with mathematics and have unfavorable opinions about it, claims Sung et al. (2017). Students are exposed to a more interesting and relevant approach to mathematics by adding CT into mathematics instruction, which might help them form a favorable opinion of the subject. Last but not least, incorporating CT into math instruction will help pupils become ready for coming technology breakthroughs. Technology improvements are transforming how we live and work, and Kaufman (2013) contends that it is crucial for students to be ready for these changes. Schools may assist prepare students for future technology developments and make sure they have the skills required to flourish in a quickly changing environment by incorporating CT into mathematics curriculum.

Students' mathematical thinking and problem-solving skills may be significantly enhanced by incorporating CT into senior primary school mathematics instruction. The findings have implications for theory and practice in a number of areas, including the growth of transferable skills, the advancement of equity in education, the facilitation of innovative teaching practices, the closing of the skills gap in the workforce, the promotion of a positive attitude toward mathematics, and preparing students for future technological advancements. For educators, decision-makers, and researchers, these results have significant theoretical and practical ramifications. Practically speaking, a fundamental change in teaching and learning methods is necessary to include CT into mathematical education. Schools must offer the resources required to promote the adoption of novel teaching techniques that involve CT, and educators must get the training necessary to create these practices. The ramifications of the findings must be understood by policymakers, and they must encourage efforts to include CT into mathematics instruction.

The incorporation of CT into ME poses theoretical challenges to conventional ideas about ME and necessitates a reexamination of what it means to be mathematically literate in the digital age. Research is required to determine the most efficient strategies to use CT in mathematics instruction as well as to pinpoint the elements that help or impede its adoption. In conclusion, the inclusion of CT in senior primary school ME has important consequences for both theory and practice. The findings imply that the inclusion of CT can enhance students' capacity for mathematical reasoning and problem-solving, as well as promote equity in education, enable creative teaching methods, close the skills gap in the workforce, foster a positive attitude toward mathematics, and prepare students for future technological advancements. These results underscore the need for more research and implementation efforts and have significant theoretical and practical ramifications for educators, decision-makers, and researchers.

## 5.3 Limitations of the Study

Although the study found significant relationships between CT and ME, as well as considerable improvements resulting from CT integration, some limitations should be noted.

One of the limitations of the study was the relatively small sample size and the fact that the study was conducted in a single school in Hong Kong. Therefore, the findings may not be generalizable to other contexts. Another limitation was the use of only a few methods of data analysis, which may have limited the reliability of the findings. Future research could include a larger sample size and use multiple methods of data analysis to increase the reliability and generalizability of the findings. Another limitation of the study was the relatively short duration of the intervention. The intervention was implemented over a period of two months, which may not have been sufficient to fully assess the long-term effectiveness of the program. Future research could explore the long-term impact of the program over a longer period of time.

The sample was diverse in terms of gender, providing a rich dataset for analysis. However, it is important to note that the study was conducted in Hong Kong and therefore the findings may not be generalizable to other cultural contexts. The specific educational and cultural context of Hong Kong may impact the results of the study, and future research in other contexts would be necessary to assess the broader generalizability of the study findings.

The small sample size and short duration of the study warrant caution in generalizing the findings. Longitudinal research could provide more comprehensive evidence on the long-term impacts of incorporating CT into ME. Future studies may also explore teachers' perspectives in depth regarding the challenges of implementing CT integration and the types of support and professional development needed.

The study of the importance of incorporating CT instruction into senior primary school mathematics curricula is crucial because it helps pupils become ready for the digital era. However, there are a number of limitations to the research that should be considered when interpreting the findings. First of all, since only senior primary school kids were the subject of the research, its reach was limited. The results may not be relevant to different age groups or educational levels as a result. For instance, since secondary school or junior primary school students could have different learning requirements and expectations, the study's findings might not be generalizable to both populations of students. Future studies should thus look at the effects of CT instruction across a range of age groups and educational levels. The study's approach is also a drawback. The research's quasi-experimental methodology may not have been the most appropriate method for assessing how well CTE has been incorporated into mathematics instruction. A more thorough experimental plan, such as a randomized controlled trial, would have given more convincing proof of the intervention's effectiveness. Furthermore, the research only included one school in its sample, limiting the applicability of the findings to other institutions. To increase the validity of the results, future research should strive to employ a bigger sample size and a more reliable experimental design.

Thirdly, the study's evaluation of the intervention's effectiveness has limitations. Pre- and post-test scores were the only quantitative metrics employed in the study to assess the intervention's effectiveness. The intricacy of the learning process and the abilities that students gain via CTE may not be completely reflected in these metrics. In order to give a more thorough evaluation of the influence of the intervention on students' learning outcomes, future research should take other research methodologies into consideration. The research just briefly discusses how teachers might help students learn CT skills as part of their math curriculum. The study did not take into account any of the variables that may help or hinder teachers in implementing the intervention; instead, it merely examined how the intervention affected students' learning results. The opinions, attitudes, and beliefs of teachers toward CTE and their contribution to making the technique more widely adopted in mathematics instruction should be the subject of future study.

Fourthly, the study's evaluation of the social and cultural environment in which the intervention was used is rather constrained. The study did not examine how cultural and societal elements, such as socioeconomic position, ethnicity, and language, affect students' learning results. Future studies should take into account the contextual variables that might have an impact on the application and efficacy of CTE, as well as how these variables could be addressed to guarantee fairness and inclusivity in education. There are a number of limitations to the research that must be considered when interpreting the findings about the importance of including CTE into senior primary school mathematics instruction. The scope, technique, evaluation of the effect, teaching function, and contextual considerations are some of these limits. To give a more thorough knowledge of the effects of CTE on students' learning outcomes and how it might be successfully incorporated into ME, future research should try to solve these shortcomings.

## 5.4 Recommendations for Future Research

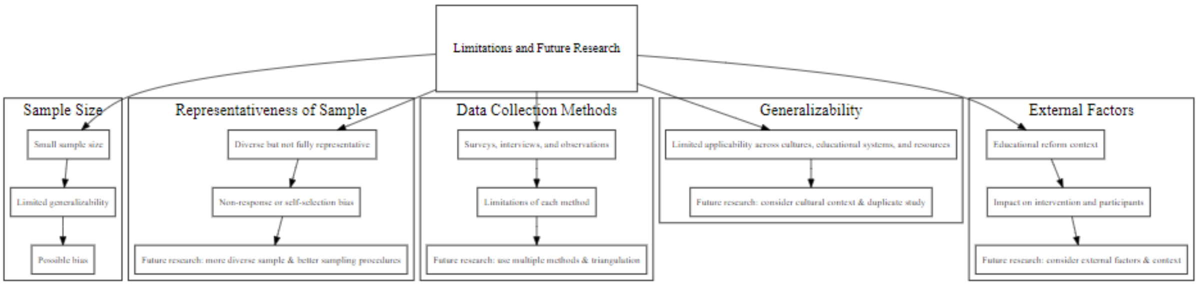



Figure 10. Limitations of the Study and Implications of Future Research

Several suggestions for future research are based on the study of the importance of incorporating CT instruction into mathematics instruction in senior primary school. Investigating the efficacy of various instructional techniques and teaching tactics that might be utilized to include CT into ME is one potential direction for future study. According to several research, project-based learning and inquiry-based learning strategies, for instance, may help students develop their CT abilities (Tondeur et al., 2016). Future studies might thus examine how these strategies affect students' engagement and learning results when integrating CT in ME.

The creation of suitable assessment methods and tools for assessing students' CT abilities within the framework of ME might be another subject of future study. There is a need for standardized assessment methods that can precisely gauge students' CT skills since CT is a relatively young field of research. This might include creating performance-based evaluations and rubrics that are in line with the guidelines and criteria for CT (Weintrop et al., 2016). Future study might also examine how professional development for teachers can support the inclusion of CT in mathematics instruction. The ability of teachers to successfully incorporate CT into their teaching practice is crucial since they play a crucial role in supporting students' learning. Future studies might thus look at how teacher professional development initiatives affect teachers' knowledge and expertise in incorporating CT into mathematics instruction.

Future studies might also look at how CT in mathematics instruction affects students' motivation and interest in the subject. According to Ketelhut et al. (2020), CT exercises may provide students the chance to participate in inquiry-based learning and creative problem-solving, which can increase their motivation and interest in mathematics. Future studies might thus look at how incorporating CT into mathematics instruction affects students' motivation, interest, and attitudes toward the subject. Future studies might also look at the possibility of incorporating CT into subjects other than mathematics, such science, technology, arts, and engineering. Integrating CT into other subject areas can give students the chance to develop a comprehensive understanding of CT and its relevance to their daily lives since it is a cross-curricular skill with applications across many disciplines (Barr et al., 2011).

Additional study is needed in the field of senior primary school mathematics instruction and CT. The effectiveness of various teaching methods, the development of appropriate assessment tools, the role of teacher professional development, the impact on students' motivation and interest, and the potential integration of CT into other subject areas are all areas that can be explored in future research. Such study will help us better understand how to improve students' learning outcomes and engagement by integrating CT into the teaching of mathematics and other subjects.

# 6. CONCLUSION

The problem of conflicting results in the association between CT and mathematics learning outcomes emphasizes the need of more study to determine how to optimize the usefulness of CT in students' mathematical learning and vice versa. Two research revealed that students' CT participation did not help their mathematical learning, despite the fact that the bulk of the studies included in the systematic review found empirical evidence of a positive link between CT and mathematics learning. In one of these studies, Chan et al. (2021) investigated how a coding exercise affected students' comprehension of mathematical ideas. Although students' coding skills increased, the authors discovered that there was no discernible difference in their comprehension of mathematics. Similar research was done by Psycharis and Kotzampasaki (2017), who looked at the connection between CT and arithmetic proficiency among Greek primary school kids. The research discovered that although CT had no impact on certain arithmetic problems, it was favorably associated with students' performance on others.

It is crucial for researchers to concentrate on the qualitative subtleties in students' learning processes rather than just the quantitative details of their learning outcomes in order to explain these discrepant findings. Researchers can pinpoint and contrast the key elements of the assignments and teaching methods that result in inconsistent learning results. One explanation, for instance, might be that the particular coding activity used by Chan et al. (2021) did not fit well with the mathematical ideas being taught or that the activity's implementation did not sufficiently support students in making the connection between their coding abilities and the mathematical content. Additionally, the effectiveness of how CT and mathematics training are integrated may possibly be a key element. If CT is not integrated well, it could not help pupils learn arithmetic, or worse, it might make it harder for them to learn math. A thorough awareness of both CT and mathematical ideas and abilities, as well as how they might complement one another, is necessary for effective integration. For teachers to successfully integrate CT and ME, they require professional development opportunities to gain this knowledge and experience.

The purpose of this research was to discover the significance of integrating CT into ME in senior primary education. The importance of this issue stems from the need of preparing pupils for a world that is changing quickly and in which digital technology is becoming more and more important. In order to highlight the major discoveries and contributions of research in this field, the study set out to review the literature on CT and mathematics instruction in senior primary schools. The study discovered that there is an expanding body of literature on the integration of CT in ME, and that this literature emphasizes the significance of CT in helping students' mathematical thinking and problem-solving abilities. CT entails a collection of methodologies and problem-solving techniques that are common in computer science and related subjects and that are applicable to a broad variety of issues and subject areas. In the context of math education, computational tools, models, and simulations are used in CT to aid students' comprehension of mathematical ideas and procedures.

The study uncovered several key findings concerning the integration of CT into ME in senior primary schools. First, incorporating CT can boost students' engagement and motivation in mathematics by making the subject more relevant and captivating. Second, CT can support the development of mathematical thinking and problem-solving skills by offering tools and approaches that encourage critical and creative thinking. Third, CT can foster students' understanding of mathematical concepts and processes by providing visual and interactive representations of these concepts and processes.

However, the study also identified several challenges and barriers to integrating CT into ME in senior primary schools. These include a lack of teacher training and expertise in CT, limited access to suitable technologies and resources, and insufficient support from school administrators and policymakers.

The findings emphasize the importance of integrating CT into ME in senior primary schools to aid students' development of mathematical thinking and problem-solving skills in a digital age. Additionally, the study suggests that there is a need for teacher training and professional development programs to facilitate the integration of CT into ME, as well as for policymakers and school administrators to supply the necessary resources and support for this integration.

The study has substantial ramifications for philosophy and practice. According to the study's results, senior primary schools' use of CT in math classes may help pupils improve their ability to think critically and solve problems mathematically as well as increase their interest in the subject. The design of educational programs and curriculum intended to include CT into mathematics teaching will be significantly impacted by these results. The study's conclusions point to CT as a useful foundation for assisting students' mathematical thinking and problem-solving abilities from a theoretical standpoint. CT offers a collection of methodologies and problem-solving techniques that are based on computer science and related topics and are applicable to a variety of issues and subject areas. Teachers may provide students a set of tools and strategies that can help their learning and growth in mathematics by incorporating CT into their curricula. From a practical standpoint, the study's findings suggest that a variety of resources and supports, including teacher training and professional development programs, access to the right tools and resources, and support from school administrators and policymakers, are needed for the integration of CT into ME. The design and execution of educational initiatives aiming at incorporating CT into mathematics instruction in senior primary schools will be significantly impacted by these results. A number of recommendations for more research may be made in light of the study's findings. First, further research is necessary to ascertain the ways in which CT influences students' motivation, engagement, and mathematical achievement. Second, research is needed to determine how programs for teacher preparation and professional development could make it easier to integrate CT into math lessons. Another idea for future research is to look at the contribution that teacher professional development makes to the successful integration of CT into mathematics teaching. Although it has been highlighted in a number of previous studies, this one did not specifically examine the importance of teacher preparation. For instance, effective teacher professional development was a crucial element in integrating CT into ME, according to Bower et al. (2017)'s study. Future research should look at the best ways to train teachers in Connecticut and how that training affects student results.

The creation and assessment of teaching resources that incorporate CT into mathematics instruction is another subject for future study. According to this research, there aren't enough high-quality, developmentally appropriate teaching resources that include CT. Future research should thus concentrate on creating and assessing instructional materials that combine CT and mathematics instruction in a manner that is interesting to and accessible to students in senior primary school. Finally, further study is required to examine how CT instruction affects students' long-term learning results. Although there is evidence that CT instruction may improve students' mathematical reasoning and problem-solving abilities, it is not apparent if these improvements are maintained over time. Future studies should look at how CT instruction affects kids' arithmetic skills over time as well as associated outcomes like enthusiasm in math and job goals.

This research emphasizes the need to include CT instruction in senior primary school mathematics curricula. According to the results, CT instruction may help students improve their mathematical reasoning and problem-solving abilities, and in order to successfully integrate it, it is crucial to provide teachers access to the right professional development opportunities and top-notch teaching resources. Despite significant drawbacks, including a small sample size, the study offers a helpful summary of the status of research on CT and mathematics instruction in senior primary schools at the time. Overall, this study adds to the growing body of knowledge on the use of CT in ME and offers critical insights for academics, teachers, and policymakers who are trying to advance students' mathematical abilities and get them ready for the challenges of a rapidly changing world.

**Concluding Remarks**

It is recommended that more study be done to investigate various uses, such as employing unplugged activities, digital tangibles, or other coding languages, given the enormous potential of CT. The findings of this research have important ramifications for ME theory and practice. The research focused on examining techniques that integrate CT into ME and learning by looking at teaching and outreach materials and artifacts. According to the study, incorporating CT into mathematics instruction may help students become better problem solvers, foster critical thinking, and foster interdisciplinary connections.

Future research may use this study's theoretical framework and methodology in a variety of ways. First, academics interested in the implications of CT might concentrate on several core or integrated disciplines, including STEM, and STEAM education, to examine the ways in which CT is incorporated into each of their unique curriculum. This could deepen the knowledge of the ramifications of CT integration across academic fields and how it might improve students' critical thinking and problem-solving abilities in varied contexts. Second, researchers might look at the integration of CT in other cities of countries, other than Hong Kong. This may provide light on the various means through which CT is included into various curricula and the methods used to promote CT in various settings. Finding the optimal methods for integrating CT in mathematics instruction might be accomplished by contrasting the viewpoints and practices in various fields and geographical areas.

Furthermore, a future study can concentrate on the curricular policy itself. To get a better understanding of the integration of CT in the mathematics curriculum, it is possible to evaluate curriculum policy documents such as policies, strategies, frameworks, guidelines, reports, resource guides, and associated policy web sites. Investigating the various areas' or nations' approaches to mathematics curricula may also be done via comparative document analysis. This kind of research may show the many methods and tactics used to enhance CT integration in mathematics instruction and point out excellent practices.

The findings of this study serve as a starting point for further investigation into mathematical instruction. To further the present knowledge of the consequences of CT and the best practices for CT integration in ME, the theoretical and methodological approach of this work may be applied to many core or integrated disciplines, regions, and data kinds. Future studies may examine curricular policies and explore CT uses outside of the block programming language. The results of this kind of study may assist further the integration of CT into mathematics instruction, improve students' capacity for problem-solving and critical thought, and foster interdisciplinary relationships.

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**TIMELINE**

| Tasks/ Milestones (*) | 2021 | | | | 2022 | | | | 2023 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jan – Mar | Apr – Jun | July – Sept | Oct – Dec | Jan – Mar | Apr – Jun | July – Sept | Oct – Dec | Jan – Mar | Apr – Jun |
| Getting Set | * | * | | | | | | | | |
| Proposal | * | * | | | | | | | | |
| Literature Review (I) | * | * | | | | | | | | |
| Submit Conference Paper - Proposal (GCCCE2021) | | * | | | | | | | | |
| Submit Manuscripts to Journals - Systematic Literature Review | | * | | | | | | | | |
| Present Conference Paper - Research Proposal (GCCCE2021) | | | * | | | | | | | |
| Publish a Journal Article - SLR of CT into ME (US-China Review) | | | * | | | | | | | |
| Submit Conference Paper - Literature Review (HKMEC2021) | | | | * | | | | | | |
| Present Conference Paper - Literature Review (HKMEC2021) | | | | | * | | | | | |
| Revise Proposal | | | | | * | * | | | | |
| Literature Review (II) | | | | | * | * | | | | |
| Submit Conference Paper - STEM Education (GCCCE2022) | | | | | | * | | | | |
| Present Conference Paper - STEM Education (GCCCE2022) | | | | | | * | | | | |
| Submit Proposal to the EdUHK | | | | | | | * | * | * | |
| Dissertation Chapters Drafted | | | | | | | * | * | * | |
| Data Collection & Organization (I) | | | | | | | * | * | * | |
| Participant recruitment | | | | | | | | * | | |
| Data collection (First Phase) | | | | | | | | * | | |
| Data Analysis (First Phase) | | | | | | | | | * | |
| Data collection and analysis (Second Phase) | | | | | | | | | * | * |
| Discuss Conclusion | | | | | | | | | * | * |
| Further Draft | | | | | | | | | | * |
| Final Meeting | | | | | | | | | | * |
| Final Draft | | | | | | | | | | * |

# Appendices A. Survey to Student Participants

**Title**: Assessing the Motivation of Grade 6 Students to Learn Mathematics Through Coding Activities in Computational Thinking Education

**Introduction**:
This survey aims to collect quantitative data from 61 Grade 6 students to address the research question: "Are students motivated to learn mathematics through coding activities in Computational Thinking education?" Your responses will help us understand the effectiveness of integrating coding activities in mathematics lessons.

Please answer the following questions by selecting the most appropriate option. Your responses will remain anonymous.

1. How much do you enjoy participating in computational thinking activities (Vinci Bot) during your mathematics lessons?
    - Strongly dislike
    - Dislike
    - Neutral
    - Like
    - Strongly like
2. Do you feel that computational thinking activities help you better understand mathematical concepts?
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree
3. Does participating in computational thinking activities make you more motivated to learn mathematics?
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree

4. Would you be interested in participating in more computational thinking activities in your mathematics lessons in the future?
    - Definitely not
    - Probably not
    - Unsure
    - Probably yes
    - Definitely yes

Thank you for participating in this survey! Your feedback will help us improve the integration of coding activities in mathematics education.

# Appendices B. Lesson Observation Checklists and Field Notes

Date:

Lesson Topic:

Observer:

Start Time - End Time:

1. Academic Performance:

- Application of CT skills to mathematical problems:
- Improvement in problem-solving capabilities observed:
- Changes in students' mathematics performance and understanding:

2. Learning Motivation:

- Student engagement and enthusiasm during coding activities:
- Level of interest in mathematics topics when CT is integrated:
- Perceived relevance of CT skills to mathematics learning:

3. Teaching Methodologies:

- Integration of coding activities within mathematics lessons:
- Use of technology in the lesson:
- Real-world examples connecting CT and mathematics:

4. Classroom Dynamics:

- Teacher's facilitation and management of the learning environment:
- Formative assessment strategies used:
- Differentiated instruction observed:

Additional Observations/Comments:

# Appendices C. Consent Form To Participate in Research

**THE EDUCATION UNIVERSITY OF HONG KONG**
**Department of Mathematics and Information Technology**

**CONSENT TO PARTICIPATE IN RESEARCH**

**The Significance of Integrating Computational Thinking Education into Mathematics Education in Senior Primary School**

I ____________________ hereby consent to participate in the captioned research supervised by Dr. POON Kin Keung and conducted by Mr. LEUNG Yu Hin, Herman, who are staff / students of Department of Mathematics and Information Technology in The Education University of Hong Kong.

I understand that information obtained from this research may be used in future research and may be published. However, my right to privacy will be retained, i.e., my personal details will not be revealed.

The procedure as set out in the **attached** information sheet has been fully explained. I understand the benefits and risks involved. My participation in the project is voluntary.

I acknowledge that I have the right to question any part of the procedure and can withdraw at any time without negative consequences.

Name of participant ____________________

Signature of participant ____________________

Date ____________________

# 香港教育大學
# 數學與資訊科技學系

## 參與研究同意書

## The Significance of Integrating Computational Thinking Education into Mathematics Education in Senior Primary School

本人____________________同意參加由潘建強博士負責監督，梁宇軒先生執行的研究項目。他們是香港教育大學數學與資訊科技學系的學生/教員。

本人理解此研究所獲得的資料可用於未來的研究和學術發表。然而本人有權保護自己的隱私，本人的個人資料將不能洩漏。

研究者已將所附資料的有關步驟向本人作了充分的解釋。本人理解可能會出現的風險。本人是自願參與這項研究。

本人理解我有權在研究過程中提出問題,並在任何時候決定退出研究，更不會因此而對研究工作產生的影響負有任何責任。

參加者姓名：

________________________________________

參加者簽名：

________________________________________

日期：

________________________________________

# Appendices D. Information Sheet

**The Significance of Integrating Computational Thinking Education into Mathematics Education in Senior Primary School**

You are invited to participate in a project supervised by Dr. POON Kin Keung and conducted by Mr. LEUNG Yu Hin, who are staff / students of the Department of Mathematics and Information Technology in The Education University of Hong Kong.

***<u>The introduction of the research</u>***
*To examine the significance and effects of integrating computational thinking (CT) into mathematics education (ME) in senior primary education.*

***<u>The methodology of the research</u>***
*A) Procedure of the research: Participants will be asked to answer 4 close-ended questions in a survey (For Survey Participants) or 2 interview questions with audio-recorded (For Interview Participants). The research will take approximately 5 minutes (For Survey Participants) and 10 minutes (For Interview Participants).*
*B) The participation in the project is voluntary, and there is no compensation for participation.*

***<u>The potential risks of the research</u>***
*A) There are no potential risks associated with the research.*
*B) Your participation in the project is voluntary. You have every right to withdraw from the study at any time without negative consequences. All information related to you will remain confidential, and will be identifiable by codes known only to the researcher.*

*The research is for the fulfillment of The research component of the EdD programme. However, electronic copies will be uploaded onto online databases managed by the University Library for internal as well as public access, which will be available for discovery via the Internet.*

If you would like to obtain more information about this study, please contact Mr. LEUNG Yu Hin, Herman at telephone number [redacted]

If you have any concerns about the conduct of this research study, please do not hesitate to contact the Human Research Ethics Committee by email at hrec@eduhk.hk or by mail to Research and Development Office, The Education University of Hong Kong.

Thank you for your interest in participating in this study.

Mr. LEUNG Yu Hin, Herman
Principal Investigator

# 有關資料

## The Significance of Integrating Computational Thinking Education into Mathematics Education in Senior Primary School

誠邀閣下參加潘建強博士負責監督，梁宇軒先生負責執行的研究計劃。他們是香港教育大學數學與資訊科技學系的教員及學員。

***研究計劃簡介***

*本研究旨在探討在高小學數學教育中融合計算思維教育的意義和效果。*

***研究方法***

*A) 研究程序：參與者將被要求在調查中回答 4 道封閉式問題（調查參與者），或接受 2 個帶有音頻錄音的訪談問題（訪談參與者）。研究將分別需要約 5 分鐘（調查參與者）和 10 分鐘（訪談參與者）的時間。*

*B）參與項目是自願的，參與者不會得到任何補償。*

*研究潛在風險*

*A）本研究沒有任何潛在風險。*

*B）閣下的參與純屬自願性質。閣下享有充分的權利在任何時候決定退出這項研究，更不會因此引致任何不良後果。凡有關閣下的資料將會保密，一切資料的編碼只有研究人員得悉。*

*本研究是教育博士（EdD）課程研究組成部分。電子副本將上傳到由大學圖書館管理的在線數據庫中，這些數據庫將供內部和公共訪問，並可通過互聯網進行檢索。*

如閣下想獲得更多有關這項研究的資料,請與梁宇軒先生聯絡，電話 [redacted]。

如閣下對這項研究的操守有任何意見,可隨時與香港教育大學人類實驗對象操守委員會聯絡（電郵：hrec@eduhk.hk ; 地址：香港教育大學研究與發展事務處）。

謝謝閣下有興趣參與這項研究。

梁宇軒先生
首席研究員