12-2023

Educational Robotics and Computational Thinking in Elementary School Students

Sonia D. Jordan
sdj16b@acu.edu

Recommended Citation

Jordan, Sonia D., "Educational Robotics and Computational Thinking in Elementary School Students" (2023). Digital Commons @ ACU, *Electronic Theses and Dissertations.* Paper 725.

This dissertation, directed and approved by the candidate's committee, has been accepted by the College of Graduate and Professional Studies of Abilene Christian University in partial fulfillment of the requirements for the degree

Doctor of Education in Organizational Leadership

Nannette W. Glenn, Ph.D.

Dr. Nannette Glenn, Dean of
the College of Graduate and
Professional Studies

Date 11 / 09 / 2023

Dissertation Committee:

Christie Bledsoe

Dr. Christie Bledsoe, Chair

Laura A. Perry, Ed.D.

Dr. Laura Perry

John A. Harrison, Ph.D.

Dr. John Harrison

Abilene Christian University

School of Educational Leadership

Educational Robotics and Computational Thinking in Elementary School Students

A dissertation submitted in partial satisfaction

of the requirements for the degree of

Doctor of Education in Organizational Leadership

by

Sonia D. Jordan

December 2023

Abstract

This study examined the role of educational robotics in fostering computational thinking in elementary settings, both in classrooms and extracurricular programs. Among growing concerns over K–12 students' computational thinking deficits, the research evaluated the impact of Lego EV3 and VEX IQ platforms. Data was sourced from lesson plans, student work surveys, and teacher interviews and then subjected to thematic analysis using a qualitative approach. The participants were Texas educators engaged in robotics instruction, even though specific robotics statistics are absent in the Texas Education Agency. Instructional strategies varied from hands-on experiences to translating mathematical concepts into robotic actions. A key finding was robotics' role in advancing computational and critical thinking skills. Teachers believed that robotics went beyond a mere science, technology, engineering, and mathematics introduction, promoting advanced computational thinking and linking creativity to real-world application. Robotics challenges were seen to enhance students' computational and critical thinking capabilities. The study drew from constructionism theory, which promotes learning through action and knowledge creation. In conclusion, educational robotics, reinforced by constructionism, is essential for equipping students for a technologically advanced future. Early exposure to robotics equips elementary students with vital 21st-century skills, enhancing their science, technology, engineering, and mathematics preparedness.

Keywords: educational robotics, computational thinking, elementary education, constructionism, science, technology, engineering, and mathematics (STEM)

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Educational robotics is becoming increasingly common in U.S. K–12 classrooms to implement activities designed to foster the development of computational thinking skills (Mizanoor Rahman, 2021). Hands-on engineering activities such as robotics promote computational thinking and positively affect students' achievement, engagement, and perceptions of science, technology, engineering, and math (STEM; Fidai et al., 2020). Educational robotics introduces hardware kits with intuitive software platforms and course plans for instructors to instruct students step-by-step. The drawback of these software platforms is that hardware kits must be obtained for hands-on experience (Jung & Won, 2018). Virtual platforms for teaching robotics and coding are available, providing financial advantages for educational environments with cost-prohibitive budgets. However, teaching robotics with digital learning is different from hands-on experiences (Jung & Won, 2018). This research study sought to understand the use of educational robotics with elementary students as they developed computational thinking.

Background of the Study

Growth of Educational Robotics Participation

The examination of educational robotics has grown as educators and administrators seek to include computer programming (coding) in the K–12 educational environment. Kafai and Burke (2014) noted that the interest that began in the 1980s has gradually gained momentum over the past several decades. The interest in educational robotics has grown because it adds a new dimension to computer programming. Computer programming has been understood to be a screen-based exercise. However, educational robotics provides an opportunity for physical computing, using tangible age-appropriate hardware for educational interpretations. Researchers have noted that educational robotics provide hands-on instructions that promote increased engagement, intrinsic motivation to learn, and a heightened interest in STEM-related activities (Bers et al., 2014; Huang et al., 2013; Nugent et al., 2010; Park, 2015; Ucgul & Cagiltay, 2014).

In 1980, Seymour Papert, a pioneer working with children learning to code, defined "computational thinking" (Papert, 1980, p. 182). Computational thinking enables children to establish ordered steps and algorithms to solve problems. Creating algorithms promotes the development of sequencing ability, a foundation for successful reading and STEM (Toh et al., 2016). More recently, the relationship between computational thinking and cognitive skills developed in early childhood has been explored. According to Sullivan & Bers (2016a), "As early as pre-kindergarten, children can master foundational concepts regarding programming a robot, and children as young as seven years old can master concepts as complex as programming a robot using conditional statements" (p. 18). Muñoz-Repiso and Caballero-González (2019) revealed that middle school students who completed learning activities using educational robotics increased their computational skills.

Increase Participation in Computer Science

The interest in promoting computer programming in schools is associated with computational thinking as a problem-solving skill (Kafai & Burke, 2014; Lye & Koh, 2014; Wing, 2006). Computational thinking is often used in educational technology. However, Kafai and Burke (2014) explained that the term is often incorrectly assumed to mean thinking like a computer. Computational thinking represents an array of strategies and problem-solving approaches (Brennan & Resnick, 2012). Although computational thinking is linked to computer programming in computer scientists and engineers, there are no limitations to the broad reverberation for how students can approach and commence solving problems in any circumstance (Wing, 2006).

Papanastasiou et al. (2019) and Sohn (2018) contended that the development of computational thinking as a problem-solving tool would impact 21st-century employability in STEM careers. Researchers enthusiastically support the integration of computational thinking as a core competency for students from prekindergarten through higher education (Grover & Pea, 2013; Shute et al., 2017). Strengthening such skills will prepare students to live and work in a rapidly changing world (Papanastasiou et al., 2019). Educational robotics has gained popularity as a tool to promote students' development of computational thinking as a vital 21st-century skill (Grover & Pea, 2013; Merino-Armero et al., 2020; Muñoz-Repiso & Caballero-González, 2019). Robotics and coding technology teach students to problem-solve structurally. Educational robotics is favored because students receive immediate feedback for their interaction and observation with the robot (Bers & Sullivan, 2019; Kazakoff et al., 2013; Nic Réamoinn & Devitt, 2019).

Computational thinking enables people to understand complex issues and create possible solutions (Leonard et al., 2017). Computational thinking has four cornerstones. These cornerstones include decomposition, pattern recognition, abstraction, and algorithmic thinking (Shute et al., 2017). Decomposition entails evaluating a complex problem and dividing it into manageable parts. Pattern recognition involves looking for similarities. Abstraction is the narrowing technique that requires focusing on the essential data and ignoring the irrelevant details (Wing, 2006). Finally, Wing (2006) contended that algorithmic thinking is a process that establishes a step-by-step process to solve the issue.

Statement of the Problem

Computational thinking is a process (Tsai et al., 2019) that uses data structures, iterations, and algorithms to construct a relevant solution based on systematic analysis (Bers & Sullivan, 2019). The lack of computational thinking skills can impede K–12 students from maximizing their academic potential, creating warranted concerns for educational leaders (Ching et al., 2018). Computational thinking is value-added for students because it reinforces learning and communication, allowing students to troubleshoot and self-correct (Zhong & Li, 2020). In recent years, educational robotics has gained popularity as an entry-level introduction to computational thinking (Chevalier et al., 2020). Students benefit academically from a foundational understanding of robotics and coding (Chevalier et al., 2020; Kong & Wang, 2019; Muñoz-Repiso & Caballero-González, 2019). The development of computational thinking skills is necessary to thrive in the current digital age, as computers are increasingly used in problem-solving. Ideally, this illustration provided teachers with insight into designing educational robotics activities for computational skill development. Wing (2006) further contended that everyone would benefit from computational skills, not just computer scientists.

The Texas Education Knowledge Skills (TEKS) provides standards for academic instruction. Computational thinking is addressed in the TEKS in math at all grade levels K–12. Technology TEKS are also included to maximize learning for student’s preparation for the workforce. The State of Texas Assessments of Academic Readiness (STAAR) is used to assess student learning identified in the TEKS. Statewide in K–12, the STAAR math scores showed deficits in student learning. The low performance in math scores identified computational thinking as an area of needed growth.

The current study involved instructors of robotics education in Texas. Robotics instructors represent a tiny percentage of the state population. There is no formal data to determine the number of robotics instructors across the state because the Texas Education Agency (TEA) does not maintain statistics on robotics instruction. Additionally, noncertified classroom instructors such as contractors or volunteers teach many extracurricular robotics programs. Robotics and coding provide an opportunity to include real-life contextual experience, promoting students' willingness to engage in authentic and experiential learning (Papanastasiou et al., 2019). There is a positive relationship between participation in educational robotics, coding, and computational thinking (Angeli & Valanides, 2020; Arfé et al., 2020; Durak et al., 2019; Günbatar, 2020; Merino-Armero et al., 2020; Min & Kim, 2020; Papavlasopoulou et al., 2020). Consistent participation in computational thinking exercises strengthens a student's ability to transfer problem-solving skills to other disciplines (Bers & Sullivan, 2019). Further research about computational thinking through educational robotics (an emerging technology) will identify early childhood learning outcomes with computational thinking and problem-solving proficiencies (Bers & Sullivan, 2019). Additionally, the current research provided educational leaders with data to enhance students' efficiency in drawing conclusions or predictions on complex or open-ended problems.

Purpose Statement

Technological innovations have dramatically changed education from multiple perspectives (Papanastasiou et al., 2019). Robotics technology has become an influential component in everyday activities. As a result, educational robotics has gained momentum as an educational tool.

The purpose of this qualitative descriptive study was to understand the role of educational robotics in elementary-aged students in developing computational thinking skills through analysis of elementary robotics instructors' experiences and observations. Some elementary schools in Texas offer educational robotics as an enrichment class for elementary students, while others as an after-school program. Researching educational robotics as a descriptive study provided data to understand educational robotics' role in developing computational skills. This systematic process contributes to the knowledge base of school administrators and policymakers to improve the pedagogical practices in early childhood education (Merriam & Tisdell, 2016).

Research Questions

The results provided educators, administrators, and parents insight into elementary students' computational thinking processes. The essential research questions for this qualitative study were as follows:

RQ1. How do instructors describe the use of educational robotics to promote critical thinking skills among elementary students?

RQ2. What are instructors' perspectives on the development of computational thinking using educational robotics?

Definition of Key Terms

Algorithms. Algorithms are the creation of a plan that shifts through data, looks for trends, and makes decision-based predictions from the previous data (Arfé et al., 2020).

Bug. A bug in the code is an error or defect in the written computer program (Noh & Lee, 2020).

Computational thinking. Computational thinking is a systematic thought process. The process approaches problem-solving by analyzing and decomposing the problem into more minor challenges. Finally, the process establishes a plan to measure and evaluate if the goal is met (Tang et al., 2020).

Constructionism. The assertion is that using tactile methods will enable higher levels of comprehension (Papert, 1980).

Critical thinking skills. The ability to evaluate and then align thoughts and actions with the evaluation using an alternate perspective (Cruz, 2019).

Educational robotics. Educational robotics uses constructionist learning theories. Kindergarten through twelfth grade (K–12) interact with age-appropriate robotic resources to design and construct, moving the experience from abstract to tangible (Bers et al., 2014).

Engineering design process. A circular cycle with six process steps for trial-and-error solutions that include identifying the problem, imagining solutions, designing a solution, creating the design, testing the design, and making improvements (Leonard et al., 2017).

EV3 Mindstorm®. The third-generation educational robotics kits designed for children by Lego®.

STEM. Acronym for science, technology, engineering, and mathematics. The stem is an integrated curriculum that includes an inclusive course for instruction (Acar et al., 2018).

VEX IQ. The educational robotics platform is designed for use in elementary and middle schools.

Chapter Summary

In recent years, robotics and coding technology have vastly grown in several industries, including K–12 education. Educational robotics is a resource that can be applied to individual subjects, practical exercises, lab classes, and projects to teach, illustrate, and practice engineering concepts. As technology advances, the requirements of analytical skills, systematic learning, creative thinking, innovative problem-solving, and contextual learning are growing in academics. Chapter 2 highlights the research literature regarding the impact of educational robotics and computational thinking on the academic achievements of elementary school children. The topics include computational thinking and STEM education, the pedagogical value of instructors, learning through coding or programming and development of computational thinking, learning through problem-solving approaches involving computational thinking, differences in gender and race regarding the effectiveness of educational robotics-based interventions in academics, students’ self-efficacy, and STEM participation.

Chapter 2: Literature Review

Educational robotics (ER) activities have become increasingly dominant in educational settings in several countries to support creative learning, innovative thinking, problem-solving, and knowledge about information technology (IT). The role of ER in enhancing computational thinking (CT) skills is worth analyzing and researching due to its growing trends. The insight into literature provides the themes in which ER and CT are influential in nurturing different aspects of education. The role of ER in fostering skills in STEM education is proven through the development of creative learning, innovative thinking, and the ability to solve problems through coding and programming (Cannon-Ruffo, 2020; Chevalier et al., 2020; Chiazzese et al., 2019).

Literature Search Methods

The literature search strategy focused on research that linked ER and CT. The initial search required a concise understanding of the history and development of computational theory. The literature search was primarily the online Abilene Christian University (ACU) library, including but not limited to Academic Source, Academic Search, Directory of Open Access Journals, and Science Direct databases. Additional search engines used included Google and Yahoo. The keywords used to conduct the search included *educational robotics*, *coding in elementary education*, and *computational thinking*.

Theoretical Framework

Papert’s (1980) constructionism theory established the relationship between ER and CT. ER provides students with opportunities to participate in constructionist learning experiences. Seymour Papert’s (1980) theory proposed that learners build knowledge through the act of constructing something. The theory contends that humankind builds knowledge through the interaction between one’s experiences and ideas. His perspective of constructivism insists that humans are the basis of the knowledge creation and acquisition process.

The constructionism framework provides opportunities for children to develop projects through hands-on engagements. A physical object provides opportunities for children to engage, explore, and experiment with relevant representations. ER can create scenarios to contextualize real-life experiences, promoting students’ willingness to engage in authentic and experiential learning (Papanastasiou et al., 2019). Resnick et al. (2009) further described the fundamental idea of constructionism as learning by doing. Several researchers have employed constructionism as a foundation for robotics and coding activities to promote coding, problem-solving, critical thinking, and collaborative skills (Papavlasopoulou et al., 2020).

Blikstein (2018) proclaimed that ER promotes thinking and learning that creates knowledge construction, allowing uninhibited creative ideas in the learning and development of education. According to Bers et al. (2002), the four pillars of constructionism are (a) learning by doing, with hands-on activities; (b) object recognition, which supports developing ways of thinking when learning about abstract phenomena; (c) powerful ideas providing connections between current knowledge and unknown real-world concepts; and (d) self-reflection facilitates mastery of intricate thinking patterns for problem-solving. When children participate in ER and coding, learning is more effective because of the authentic contexts (Lye & Koh, 2014; Slangen et al., 2011).

Learning by doing, also known as experiential learning, is a method of acquiring knowledge and skills through direct experience or practice (Scogin et al., 2017). Kolb (1984) defined experiential learning as a pedagogy that uses experiences and abstract models. The theory suggests that this method can be an effective way to learn because students tend to perform better on assessments and retain information longer because it allows individuals to actively engage with the material and apply it to real-world settings. Mayoral-Rodríguez et al. (2018) concluded that students who participated in experiential learning activities had better problem-solving skills than students who only received traditional instruction. Kong (2021) found that students who learn through hands-on activities report higher learning engagement and better learning outcomes than students who did not participate in experiential learning.

Moye et al. (2017) concluded that students learn standards-based curriculum by doing hands-on activities. However, most curriculum identifies very few opportunities for tinkering, troubleshooting, or problem-solving using hands-on activities. Skills learned by doing encourage students to apply learned knowledge to other situations and to identify and create solutions for unexpected problems without specific instruction. Problem-solving involves more ingenuity, learning from failure, and the willingness to persevere (Moye et al., 2017).

Knowledge is not instructor-transmitted but something constructed, originating from the student’s thoughts and, therefore, ensuring enthusiastic learning (Papert, 1980). This pedagogy suggests that instructors become knowledge facilitators rather than knowledge transmitters. When the pedagogy moves toward constructionism, the learner needs an object to be built. Papert (1980) suggested that learning is most effective when the learner builds real-world objects for recognition. Object recognition promotes the knowledge that is constructed within the learner’s mind based on existing knowledge and builds on new encounters. Bers et al. (2002) suggested that students who were taught using object recognition could better connect abstract concepts and real-world objects, thus creating a better understanding and visualization of complex ideas.

Powerful ideas are fundamental concepts useful to understanding a particular subject or field of study. In elementary education, powerful ideas connect different subjects to help students see the connection between what they are learning and real-world concepts. Holbert (2016) explained that powerful ideas are connectors that not only provide explanations of infinite phenomena but also provide a gateway entry for understanding other unknown concepts or principles. A powerful idea provides insight into concepts or theories of other bigger ideas (Papert, 1980). When students are exposed to powerful ideas, they are able to understand the relevance of the concepts they are studying and its application to the real world more easily. Powerful ideas promote diversity of growth with new encounters, concepts, and viewpoints (Kelter et al., 2021; Makri et al., 2015). Papert (1980) suggested, “Powerful ideas themselves are the most powerful of powerful ideas” (p. 76). Powerful ideas are associated with other ideas, including (a) individual to the pupil and (b) directly involved in providing answers for problems of personal significance (Papert, 2000).

Constructionism proposes that learners construct individualized identification and understanding of the world through experiences and reflection on those experiences (Papert, 1980). When students grapple with learning new concepts, they build an association of new experiences with their current knowledge. Knowledge growth revolves around building an object to think with and self-reflection during the current experience to construct meaning (Byrne et al., 2021). Reflections foster contemplation, which helps to facilitate mastery of more intricate thinking patterns for problem-solving (Morado et al., 2021). Slangen et al. (2011) contended that ER students could use the constructivism principles learned across several curriculum content areas, including but not limited to STEM.

Literature Review

Computational Thinking and STEM Education

The demand for STEM education is multiplying due to advancements in these fields (Cannon-Ruffo, 2020). Identifying instructional methods to foster STEM education in the K–12 environment is vital for the economic viability of countries like the United States. In a research thesis, Cannon-Ruffo (2020) presented a novel concept of STEM learning through ER that works on the theories of constructionism and CT (Cannon-Ruffo, 2020). Various research studies show significant improvement in STEM education through ER intervention (Cannon-Ruffo, 2020; Chevalier et al., 2020; Chiazzese et al., 2019). The intervention measures and results are useful for curriculum designers to integrate ER-based methods for educational environments that will lay a solid foundation for STEM learning and attainment (Cannon-Ruffo, 2020).

The relationship between ER and educational attainment in STEM education was significant in different studies (Chiazzese et al., 2019). Researchers have focused on developing CT skills among K–12 students of different subject groups (Reich-Stiebert et al., 2020). A positive relationship exists between robotics-based tasks and students learning CT skills (Chiazzese et al., 2019). More time spent by the students solving the robotics-based tasks leads to better development of their CT skills. Similarly, STEM training favors academic achievement in science and mathematics (Acar et al., 2018). Moreover, students with extended training are more likely to take more courses in the future (Acar et al., 2018). Acar et al. (2018) reminded scholars that STEM training does not explicitly include ER, but the theoretical background of ER comes from core fields in science and mathematics that require students' keen interest in growing their skills.

Computational Thinking Curriculum

The challenges for instructors and curriculum designers are increasing to strengthen CT concepts and increase students' collaborative learning (Baroutsis et al., 2019). In a research study, Baroutsis et al. (2019) designed a learning activity in which students of year 2 classes analyzed the coding sequences (of varying complexity) for solving simple problems using Beebots. The results showed the effectiveness in students' engagement in higher-order thinking skills (Baroutsis et al., 2019). As the instructors focus more on the "technology" and "engineering" of STEM, the learning opportunities for students are increasing manifold (Sullivan & Bers, 2016b). Children tend to develop programming and robotics skills even early and become proficient in solving intricate coding tasks in their higher classes (Sullivan & Bers, 2016b). The research showed statistically significant results in understanding complex mathematical concepts based on the active pedagogical design that incorporates motivation, fun, and interest in the content studied (Sáez-López et al., 2019).

Bers and Sullivan (2019) researched the impact of the application of childhood robotics on the mental development, CT skills, and creative thinking of children in early years education programs. The researchers developed a pedagogical design model, "Coding as a Playground," to inspire the utilization of ER in the classroom environment (Bers & Sullivan, 2019). The Positive Technological Development (PTD) framework developed by the researchers included the KIBO robotics kit for boosting CT skills as a unique tool for young children (Bers & Sullivan, 2019). The research study included 172 preschool children aged 3–5 years from three Spanish early childhood centers (Bers & Sullivan, 2019). The results showed positive effects of introducing robotics in education for students even before 3 years of age (Bers & Sullivan, 2019). The instructors showed confidence in applying different coding and programming tasks in their classrooms to nurture CT in their formal settings (Bers & Sullivan, 2019). As the children grow, they will carry these skills and capabilities to solve complex tasks and problems (Bers & Sullivan, 2019).

Instructors should induce problem-solving and creative-thinking skills by allowing students to design coding systems for problems with multiple solutions (Baroutsis et al., 2019). Moreover, ER stimulates CT skills among students (Baroutsis et al., 2019). Digital learning opportunities in modern classrooms raise students’ computational intelligence levels (Sullivan & Bers, 2016b). As the students learn through robotics, their mind learns to analyze problems from different dimensions. Robotics student participants learn systems thinking and decomposition approaches to tackle different problems and develop a feasible solution (Sáez-López et al., 2019).

Chevalier et al. (2020) designed a robust model for creative computational problem-solving through ER. The significant contribution of this research work is designing a framework for implementing ER to foster CT skills (Chevalier et al., 2020). The authors discussed the practical implications of ER, curriculum requirements, and constraints for instructors (Chevalier et al., 2020). Moreover, the researchers provided a model that allowed instructors to identify relevant CT concepts for different phases of ER activities (Chevalier et al., 2020).

Educational Robotics Platforms

Lego® EV3 is an ER platform designed for elementary school students. The robot kits consist of building blocks, motors, and sensors that can be assembled to create a variety of robots completing several tasks (Lego Education, 2023). The EV3 robot is directed by a programmable brick serving as the robot’s brain. Using a graphical programming language can also control the robot. The platform aims to instruct children on robotics, programming, and engineering basics.

Currently, the robotic platform is used in several educational settings, which include but are not limited to classrooms, after-school programs, and science clubs. The Lego® EV3 platform has a vast community of users, facilitating learning and experimentation support.

VEX IQ, on the other hand, is a more advanced ER platform. It is designed for beginners starting in elementary school to more advanced students in middle and high school. The Vex Robotics (2023) platform is designed for competitions and provides more challenging experiences to those interested in engineering and programming. The platform includes a programmable brain, several sensors, and multiple motors. The VEX IQ robot can be controlled by a remote and by using a graphical programming language. The VEX IQ model includes local, state, and world championship level competitions (Vex Robotics, 2023). The platform users have several resources available if the team desires to participate in an event or challenge.

Both Lego® EV3 and VEX IQ are popular robotics platforms used in education and are available worldwide. While Lego® is intended for beginners in primary school, it also provides user-friendly instructions for those inexperienced with robotics and coding; VEX IQ is designed for more experienced users and provides a more challenging and competitive experience.

Educational Impact of Educational Robotics

ER-based education promotes higher-order learning skills for students by visualizing the problems in diverse domains and decomposing complex problems into small blocks (Aggarwal, 2011; Baroutsis et al., 2019; Chevalier et al., 2020). Self-efficacy in programming also induces different programming skills and CT functioning, strengthening students' cognitive and noncognitive behaviors for academic attainment (Arfé et al., 2020; Avcu & Ayverdi, 2020). The literature also explored the role of gender in developing CT skills. It showed that boys are more interested in coding and programming in STEM education, while girls are more interested in collaboration and creativity (Angeli & Valanides, 2020). The proposed study will contribute to the research field of ER-based education and its impact on CT skills for elementary school children by emphasizing different intervention measures that promote problem-solving, decision-making, and syntactic learning.

Most of the literature regarding the application of robotics in STEM education focuses on short-duration intervention measures (Zhang et al., 2021). To achieve sustainable growth in observing STEM outcomes, instructors and curriculum designers should regularly monitor the effectiveness of robotics in different aspects of STEM education (Zhang et al., 2021). As the students advance to higher-level classes, the instructors could expose them to technologies like virtual reality, animation, and 3D programming to raise the level of STEM attainment (Zhang et al., 2021). Through ER, students learn different aspects of technology, particularly the application of robotics in real life (Castro et al., 2018). The technological and engineering knowledge of the students increases through awareness of robotics in education (Castro et al., 2018). Moreover, the CT skills and motivation to learn STEM subjects come from the attractive learning environment that could be created through robotics and other technological games (Barak & Assal, 2018). Knowledge and contextual awareness of complex subjects like STEM require rigorous CT and high motivation (Barak & Assal, 2018).

The impact of ER on students’ cognitive, social, and moral skills is worth exploring (Toh et al., 2016). Robotics encourages students to spend more time learning technology and engineering designs that form an essential part of CT (Durak & Saritepeci, 2018; Durak et al., 2019; Toh et al., 2016). During the past decade, with the radical changes in the way instructors deliver instruction through technological aids like robotics, the learning environment has become more conducive to learning technology and science (Toh et al., 2016). Moreover, the relationship between the levels of CT and reflective thinking related to problem-solving is vital, which shows that programming, coding, and robotics could instill decision-making and problem-resolution skills (Durak et al., 2019). Through robotics and technological aids, students can quickly develop programming self-efficacy that would benefit their future careers and learning curve (Durak et al., 2019). The students can overcome their weaknesses in different areas of STEM education by seeking assistance from semantic learning through ER (Acar et al., 2018). Institutions could arrange specialized courses to train their students in STEM areas through ER (Acar et al., 2018).

Coding or Programming and Computational Thinking

CT represents a universally desirable attribute that every student and professional must possess, irrespective of the field (Papavlasopoulou et al., 2020). The CT functioning and skills enhance the mental capabilities of students in a diverse range of fields, including STEM, linguistics, and artistic design (Papavlasopoulou et al., 2020). Therefore, implementing CT through ER and coding or programming in educational regimes fosters higher academic achievements and practical decision-making skills (Acar et al., 2018; Arfé et al., 2020; Cannon-Ruffo, 2020). When instructors introduce basic coding and programming in early school education, the students develop CT skills by building basic programming blocks and strategy-making to accomplish small goals (Arfé et al., 2020; Bers & Sullivan, 2019).

Improving programming self-efficacy could be quite useful for inducing CT skills among talented students. Avcu and Ayverdi (2020) analyzed the significance of the relationship between the computer programming self-efficacy of highly skilled students and their CT skills. The researchers measured CT skills and computer programming self-efficacy using relevant standards (Avcu & Ayverdi, 2020). The statistical results demonstrated a significant positive association between computer programming self-efficacy and CT skills among talented students

(Avcu & Ayverdi, 2020). Thus, the research results supported the idea that computer programming self-efficacy influences CT skills (Avcu & Ayverdi, 2020). This study provided the noncognitive aspects of CT behavior among students. These results complement the research regarding cognitive development among students to demonstrate CT functioning and behavior (Chevalier et al., 2020; Günbatar, 2020; Stewart et al., 2021). As students practice programming and coding skills in STEM education, the behavioral approach facilitates creative learning, a desirable objective from a CT perspective (Chevalier et al., 2020).

Researchers have analyzed the positive impact of coding and programming on students' decision-making and creative thinking skills. The research effort of Arfé et al. (2020) explored the effects of programming skills on children's cognitive development. Through a cluster randomized controlled trial, the researchers analyzed the impact of coding skills of first-grade children on important cognitive functions of planning and response inhibition (Arfé et al., 2020). The study's results showed that the children who used coding.org improved their ability to solve programming tasks and their executive functions like planning tasks and the inhibition of the prepotent responses (Arfé et al., 2020). Thus, coding and programming enhance academic outcomes and strengthen behavioral and problem-solving skills, as supported by different studies (Baroutsis et al., 2019; Papavlasopoulou et al., 2020). The mental growth of the students in perceiving different problems and tackling them through programming depends on their educational interventions and academic environment to promote technology and ER-based education (Julià & Antolí, 2016; Negrini & Giang, 2019).

The literature also provided valuable insight into the benefits of learning programming and coding for students to develop creative thinking and deepen understanding regarding the introduction of CT skills in the school curriculum (Arfé et al., 2020). Moreover, these benefits are essential from the pedagogical design point of view for strengthening the aspects related to CT and programming in different courses (Arfé et al., 2020). By designing coding lectures, instructors can quickly scaffold the CT skills and abilities that positively impact cognitive skills (Arfé et al., 2020). The students are able to diversify their knowledge and skills regarding applications of CT functioning in engineering, mathematics, and other subjects that require programming and visualization (Julià & Antolí, 2016; Negrini & Giang, 2019).

Developing Students' Executive Functions

According to Kim et al. (2021), "Executive functions are domain-general cognitive skills that predict foundational academic skills such as literacy and numeracy" (p. 2119). As students develop, the environment of the institutions and curriculum designs should nurture their executive functions as a set of creative and CT skills (Arfé et al., 2020). Academic institutions strive to polish children's executive functions for better career opportunities and well-being (Acar et al., 2018; Arfé et al., 2020; Cannon-Ruffo, 2020). Few researchers have discussed boosting cognitive skills, critical thinking, and executive functioning through a curriculum designed for primary or secondary schools (Avcu & Ayverdi, 2020; Da Cruz Alves et al., 2019). Arfé et al. (2020) analyzed the role of coding in the primary grades for improving students' cognitive functioning performance. Arfé et al. (2020) used randomized controlled trials by using an intervention measure of 1-month coding activities and assessed the impact of these skills on CT and creative thinking capabilities (Arfé et al., 2020). There is a clear advantage to using coding and programming exercises in the curriculum to boost students' CT functioning (Arfé et al., 2020). Children's spontaneous executive function development depends heavily on CT skills and cognitive load. Therefore, the governments of multiple countries must focus on designing academic curricula based on the modern century’s requirements regarding technological assistance, ER, and programming interventions.

One of the most underinvestigated fields is the measurement of CT skills objectively, which entails the efficacy of applying programming or coding tasks or ER (Günbatar, 2020). Computer programming attitude and computer programming self-efficacy could provide a practical quantitative assessment of CT skills among students for examining CT skills and programming attitudes (Günbatar, 2020). With the help of different courses and intervention measures, instructors and instructional designers can improve student CT scores. The instructors could design specialized tasks for children to examine their interest in programming skills and CT functioning and enhance their mental growth in scientific disciplines (Avcu & Ayverdi, 2020; Da Cruz Alves et al., 2019). Moreover, the instructors could foster the STEM education and contextual development of these subjects through CT skills and assess this functioning regularly to maintain academic attainment (Avcu & Ayverdi, 2020; Da Cruz Alves et al., 2019).

Some studies (Avcu & Ayverdi, 2020; Bers et al., 2014; Günbatar, 2020) supported the development of a framework including specialized courses for IT and robotics for nurturing creative thinking and programming skills. Moreover, these actions will enhance the objective scoring of CT behaviors. While supervising the CT functioning, the instructors will realize the roadmap toward sustainability in technological and STEM education (Avcu & Ayverdi, 2020; Da Cruz Alves et al., 2019). As the students move from primary to secondary schools and then to higher educational levels, their CT assessment becomes important in diagnosing cognitive functioning and mental health (Avcu & Ayverdi, 2020; Da Cruz Alves et al., 2019).

Technological Innovations in Educational Robotics

Children encounter technological innovations and robotics in their daily lives, enabling them to get hands-on experiences with scientific features (Kazakoff et al., 2013). Examples are automatic hand dryers, towel dispensers, automatic doors, and robotic vacuum cleaners (Kazakoff et al., 2013). The distinct features of ER enhance the vision of the students regarding the conceptualization of robots and the systems of robots (Jung & Won, 2018). The robots have human-like features and provide a mechanical understanding of various concepts that assist in building visualizations. The actual hardware and hidden software features provide the feeling of building blocks. When ER acts in a specific manner, the students learn systematic problem-solving and syntactic skills (Jung & Won, 2018). Young children could enhance their conceptual ideology about programming and coding by observing the motion of robots (Jung & Won, 2018).

The technological and psychological perspectives of ER-based learning are essential to fostering valuable concepts in the minds of young students (Jung & Won, 2018). Moreover, the students could get involved in story-based tasks or games through robotics to transform anthropomorphic perspectives into technological vision (Jung & Won, 2018). As students learn robotics-based tasks and programming languages in the classrooms, their sequencing capabilities improve (Kazakoff et al., 2013). Hand-on experiences with educational robots, gaming experiences, and strategic toys cultivate engineering design concepts in students’ minds (Kazakoff et al., 2013). Considering these research findings, instructional designers need to implement basic-level robotics in their classroom environment for better scientific perception, engineering design focus, creative problem-solving, and syntactic learning.

Teaching Through Computational Thinking Processes

There is a positive association between ER and systematic learning of scientific concepts (Arfé et al., 2020; Barak & Assal, 2018; Cannon-Ruffo, 2020; Chevalier et al., 2020). Nevertheless, realizing the true potential of robotics and programming languages depends on the design of the classroom environment and course contents (Barak & Assal, 2018). In most conventional classrooms, only some students can grasp the context and real-world application of the STEM fields (Barak & Assal, 2018). To nurture healthy concepts among all students, instructors must introduce favorable ER activities and creative problem-solving tasks (Barak & Assal, 2018).

The programming skills for children are not limited to coding but include opportunities for CT functions that involve problem-solving through abstraction and decomposition (Lye & Koh, 2014). Research scholars have presented the three dimensions of CT skills as concepts, practices, and perspectives (Lye & Koh, 2014). Due to the availability of accessible and user-friendly programming languages, educational curriculum designers include them in courses for K–12 students to familiarize them with programming and syntactic learning (Lye & Koh, 2014). Programming and robotics’ role in improving CT skills and computer sciences is also relevant (Negrini & Giang, 2019). Technological innovation, including robotics and programming, could effectively raise the students’ interest in solving engineering design and computer science problems (Negrini & Giang, 2019).

The practical learning of students emerges from the environment of meaningful content and relevance of the activity (Papavlasopoulou et al., 2020). Educational themes that include real-life settings support psychological and sociocultural elements for effectively incorporating CT elements (Papavlasopoulou et al., 2020). When students perceive meaningful context in their subjects, their minds automatically create artifacts or spatial cognition to realize the world physically (Barak & Assal, 2018). The robots trigger children's creative imagination as they often imagine robots replacing people in performing different tasks (Barak & Assal, 2018). ER integrated with programming activities often provide the benefits of teaching STEM fields, broadening scientific inquiry, and reducing psychological and cultural barriers to learning science and technology (Barak & Assal, 2018).

Programming Languages Support Computational Thinking Concepts

Robotics and visual programming languages strengthen students' mathematical and scientific foundation for learning (Sáez-López et al., 2019). Based on active methodologies to implement programming through visual tools and ER, the students can learn motion, engineering design, robotics applications, sequences, and conditionals (Sáez-López et al., 2019). The acquisition of computational concepts and technological learning stems from enthusiasm, motivation, commitment, fun, and interest in the content studied (Sáez-López et al., 2019). The programming activities could boost individualistic behavior to solve complex problems through decomposition and sequencing and allow active taxonomy for active learning experiences (Sáez-López et al., 2019). The growing trends of robotics and programming in education are leading to career opportunities in scientific learning, artificial intelligence, and data mining (Sohn, 2018). Technology assists in creating different landscapes in promoting scientific learning and knowledge acquisition (Sohn, 2018).

The research demonstrated a fruitful acquisition of computational concepts, mathematical models, and scientific ideas when working with approaches that require the active participation of students (Sáez-López et al., 2019). The students must show fun, motivation, enthusiasm, and fun while attending the programming or robotics courses to achieve the desired academic attainment (Sáez-López et al., 2019). The students favor incorporating technology-oriented tasks in their educational curriculum that require collaboration and active learning from the students. Sáez-López et al. (2019) also stated the advantages of teaching coordinates, mechanical motions, engineering design concepts, values, and integer numbers as motivation for students to learn the operation of robotics and its related applications. By focusing on teamwork and collaboration, motivation multiplies due to the synergy of efforts, and the students can achieve the highest academic outcomes in a healthy learning environment (Avcu & Ayverdi, 2020; Chiazzese et al., 2019; Ching et al., 2018; Zhang et al., 2021).

As the students grow from basic programming to advanced computational skills throughout their K–12 education, their psychological and metacognitive abilities also increase (Sáez-López et al., 2019). The primary themes of sequences and loops provide syntactic learning for students in early grades, while more sophisticated robots enhance real-life visualization of the engineering applications that involve robotics and computer programming (Sáez-López et al., 2019). When students use ER with visual programming in mathematics or other subjects related to coordinates and integers, they can apply the mathematical concepts they learn in classes to applications in the visual programming units (Sáez-López et al., 2019). Other researchers also supported this idea and proposed that ER-based interventions, technological interventions, video games, and strategic programming tasks could increase the motivation of students to achieve better results in complex subjects (Acar et al., 2018; Avcu & Ayverdi, 2020; Cannon-Ruffo, 2020; Günbatar, 2020). Moreover, the CT functioning of students improves through these educational learning opportunities.

Predictors and Lasting Impact of Teaching Computational Thinking

CT skills stem from multiple factors and predictors that are important in leading toward the desired competency level (Stewart et al., 2021). Instructors could set learning outcomes for students in a specific way to strengthen competency skills in the niches of problem-solving and innovative designing (Cannon-Ruffo, 2020; Chiazzese et al., 2019). The researchers found problem-solving to be one of the strongest predictors of CT skills (Arfé et al., 2020; Avcu & Ayverdi, 2020; Stewart et al., 2021). According to the cognitive evaluation theory, students could develop learning styles, feelings toward teamwork and collaborative tasks, learning motivation, perceived motivation, and other aspects of problem-solving skills by applying technological or programming tasks in educational settings (Stewart et al., 2021). In a collaborative robotic environment, the preferred learning model for students is teamwork, enhancing perceived competence in building and programming a robot (Stewart et al., 2021). Students tend to enjoy their tasks when integrated with robotics and programming, increasing their chances of developing core CT competencies.

Applying robotics and programming elements in educational settings requires consideration of traits that lead to higher achievement in STEM fields and programming (Strawhacker et al., 2018). Educators must show flexibility in terms of responsiveness to the requirements of students, lesson planning, expertise in technological content, and the concern for developing CT strategies and independent thinking (Strawhacker et al., 2018). The implications of developing CT strategies in different fields include enhancing collaborative learning, applying sequencing tasks to solve problems, and creative task planning to achieve higher academic success (Strawhacker et al., 2018). In some cases, the open-ended design of the computational tasks broadens the vision of the students to solve complex tasks (Strawhacker et al., 2018).

Integrating robotics and programming in early childhood education increases the chances for students to grasp important concepts of sciences and technology (Sullivan & Bers, 2016a). Robotics provides a playful and collaborative way for students to engage in healthy activities of learning STEM fields. Countries like Singapore, the United States, and the United Kingdom strive to implement robotics in their early school programs to make their young students learn core scientific disciplines easily (Sullivan & Bers, 2016a). The instructors in such academic settings must provide an interactive and collaborative environment to engage with the school community to foster programming and sequential development skills (Sullivan & Bers, 2016a). Young children develop their opinions regarding different forms of technological innovation that lead to exciting engineering designs and robotics (Sullivan & Bers, 2016a).

Durak et al. (2019) determined the skills of secondary school students regarding programming self-efficacy, CT, and reflective thinking in different problem-solving situations. Also, they examined their experiences in the programming training process on different kinds of robotics activities (Durak et al., 2019). The researchers analyzed the performance of 55 seventh- and eighth-grade students at a secondary school in the Western Black Sea region of Turkey from 2017 to 2018 (Durak et al., 2019). The study utilized a mixed-model approach and various scales in the quantitative dimension (Durak et al., 2019). The study’s results showed a moderate level of improvement in programming skills, CT functioning, reflecting thinking, and programming self-efficacy (Durak et al., 2019). Depending on the grade level, programming self-efficacy varies (Durak et al., 2019). Thus, the researchers established a positive relationship between ER or programming tasks on reflective thinking and programming self-efficacy (Durak et al., 2019).

Computational Thinking

There is an initiative to promote the participation of girls in math and science. In the study, the participants included boys and girls in a coed classroom. There was a potential that the instructor would observe differences in learning because gender differences exist in terms of applying skills in programming, robotics, and CT functioning (Sullivan & Bers, 2016b). The research showed that boys' performance is superior to that of girls in solving complex programming tasks such as repeat loops with different application parameters (Sullivan & Bers, 2016b). This difference may be due to a lack of confidence among girls in early school settings (Sullivan & Bers, 2016b). The behavior of the gender is also different in solving mathematical problems (Sullivan & Bers, 2016b). For example, the girls prefer solving mathematical questions using modeling or counting strategies. However, boys use abstract strategies they already know to solve mathematical complexities (Sullivan & Bers, 2016b). Therefore, boys outperform girls in different STEM field tasks requiring a systematic learning approach (Sullivan & Bers, 2016b).

The role of gender is vital in learning CT skills through different educational scaffolding activities (Angeli & Valanides, 2020). The learning pattern of boys is different from that of girls depending on their behavioral approach, mental models, and sequencing skills (Angeli & Valanides, 2020). The research showed that the boys seem to benefit more from ER involving kinesthetic, individualistic, and manipulative-based activities with the help of cards (Angeli & Valanides, 2020). However, the girls benefitted more from the collaborative tasks that involved teamwork.

The research studies showed successful learning experiences from ER-based education for both genders (Jung & Won, 2018). In the literature regarding gender differences and CT functioning, ER focuses on the academic achievements that provide significance of the association of technological interventions and robotics with higher perception and learning in STEM fields (Jung & Won, 2018). Gender should only be considered as a biological construction, cultural aspect, or social norm to indicate different behaviors and approaches toward technological interventions (Jung & Won, 2018). Boys and girls benefit from hands-on experiential learning and robotics because results can lead to increased engagement and motivation in stem subjects and improved problem-solving skills and spatial reasoning abilities. Moreover, the young students' behavioral learning and observational approach follow similar patterns irrespective of gender (Jung & Won, 2018). The masculine image of the STEM fields in terms of professional careers should not mask the significance of robotics and programming for girls' behavioral and conceptual development. However, more research is required to investigate the nontechnical features like race, culture, ethnicity, language, and socioeconomic class that would impact learning STEM education through robotics and programming languages (Jung & Won, 2018).

The role of racial, ethnic, and gender differences must be negated in STEM and non-STEM schools (LaForce et al., 2019). In comparison, most schools provide equal opportunities for all students to access digital tools, robotics, and programming (LaForce et al., 2019). However, access equity does not solve race and gender identity problems in educational settings (LaForce et al., 2019). Schools' strategic planning and pedagogical design should be diverse and provide radical STEM and non-STEM opportunities to grow in a meaningful sense for students to negate differentiating elements (LaForce et al., 2019). The corrective measures in the educational design should include negating long-standing gender and racial issues.

The gender differences surface as disparities in current STEM jobs. Several studies have documented the lack of female STEM jobs. According to the National Science Board (2014) data, women are underrepresented in the highest-paying STEM fields, such as computer science and engineering. Additionally, women comprise only 29% of the STEM workforce in the United States. The National Center for Women and Information Technology (2020) reported that women hold only 25% of the professional computing jobs in the United States.

In some cases, gender role motivates different aspects of education among boys and gender. For example, the boys show interest in coding, computer sciences, engineering, and robotics. However, the girls show a fascination for creative and collaborative tasks that could align indirectly with STEM education (Negrini & Giang, 2019). Therefore, the perceived impact of gender may differ depending on the field of education and the relevant outcome in the development of CT skills or teamwork and collaboration (Negrini & Giang, 2019).

Teaching programming through robotics improves CT skills irrespective of gender, as demonstrated in various studies (Noh & Lee, 2020). However, the motivation for learning scientific concepts and creativity to solve different problems may differ among boys and girls. The experimental setups showed that girls were more interested in creative tasks and activities requiring emotional intelligence (Noh & Lee, 2020). However, the boys showed more affection for scientific disciplines and engineering subjects through programming and robotics (Angeli & Valanides, 2020). This result implies that instructional designers should strategize according to gender diversity to achieve equality of academic achievements and outcomes satisfactorily (Noh & Lee, 2020).

Overall, boys and girls benefit from programming and coding tasks in their educational environment due to the ease of availability and the role of instructors in making them familiar with the latest technology in robotics (Sullivan & Bers, 2016a). Moreover, the instructors could design and implement a classroom environment that creates equal opportunities for both genders regarding educational attainment (Sullivan & Bers, 2016b). Exposure to ER at an early age, particularly for girls, has the potential to increase their interest and participation in STEM fields. The educational attainment for girls in STEM fields, creative thinking, and innovative problem-solving domains could improve with instructors' consistent efforts and dedication (Sullivan & Bers, 2016b).

Addressing gender disparity between men and women in pursuing technological innovation, scientific disciplines, engineering, and computer sciences is vital to enhancing equal opportunities for both genders in markets (Sullivan & Bers, 2019). The attitudes and behaviors of the gender toward different disciplines are interesting to minimize the gaps in learning them (Sullivan & Bers, 2019). Boys and girls perform differently in deep programming tasks due to the higher focus of boys on core programming and robotics skills (Sullivan & Bers, 2019). Boys' attitude toward CT functioning and robotics is more favorable than girls (Vandenberg et al., 2021). The curriculum should include positive intervention measures to arouse girls' interest in STEM fields to enhance the girls' vision in the early childhood education setting (Sullivan & Bers, 2019). The girls' access to technological innovations and creative thinking opportunities could reduce the disparity of gender differences (Sullivan & Bers, 2019).

The research evidence also indicated that the role of female instructors was important in empowering girls to participate in complex programming activities and STEM areas (Sullivan & Bers, 2016b). Female instructors could reduce gender disparities in educational setups by equalizing STEM achievement through strategic measures (Sullivan & Bers, 2016b). Practitioners should expose children to different STEM role models from a variety of backgrounds, genders, experiences, and ethnicities (Sullivan & Bers, 2016b). While the current research does not include gender data, gender is included in the literature because it is a vital variable to consider as educators provide ER and STEM instruction.

Significance of ER in the Educational System

The application of ER in educational systems around the globe is snowballing due to its proven efficacy in nurturing CT skills. The research effort of Bers et al. (2014) highlighted the challenges regarding integrating ER skills into the educational curriculum formally. Bers et al. (2014) developed a robotics program to integrate computer programming and robotics tools into the curriculum of kindergarten students. The research effort analyzed the impact of applying ER-based tools in kindergarten classrooms concerning CT skills (Bers et al., 2014). The results supported the claims that kindergarten students felt motivated to participate in robotics-based tasks to arouse innovative and problem-solving skills (Bers et al., 2014). With the help of robotics, young students can quickly learn the programming basics and apply them in their lives to challenge complex problems (Bers et al., 2014).

The research study by Da Cruz Alves et al. (2019) analyzed the approaches to assess CT skills competencies based on code analysis in K–12 education as a systematic mapping study (Da Cruz Alves et al., 2019). The researchers identified 14 methodologies to engage K–12 students in CT functioning, focusing on the analysis related to programming and coding (Da Cruz Alves et al., 2019). However, the research study contained an apparent lack related to the assessment criteria and feedback of instructors that would require further research to encompass a wide range of computing education competencies for K–12 students (Da Cruz Alves et al., 2019). The assessment methods could include surveys, questionnaires, or interview observations that would provide a more comprehensive picture related to CT practices and perspectives.

Conceptualization and modeling of CT skills are essential for assessing the current level of technological implementation in academics and the deficiencies in complying with the required standards (Tang et al., 2020). Most CT assessments in research focus on computer programming or computing skills, and surveys measure CT dispositions (Tang et al., 2020). For effective utilization of CT functioning, the applications of tools like ER, programming, and coding should be vigilantly monitored in classrooms (Tang et al., 2020). The researchers recommend building a systematic database to search for a collection, searching, and assessment of CT tools.

Raj Aggarwal (2011) analyzed the fundamental driving forces for globalization, including sustainability, demographics, and technology. The business influence of these driving forces is significant, creating plenty of challenges for students (Aggarwal, 2011). Demographic forces are creating uncertainties in the employees’ population and government finances, the sustainability issues raise challenges for the world economy, and the rise of economies like Brazil, China, and India is restricting the global economy (Aggarwal, 2011). Due to the highly unpredictable nature of the global economic forces and challenges, the instructional design requirements that schools must consider the development of behaviors, skills, and knowledge that would be useful for the career opportunities for the students (Chiazzese et al., 2019; Stewart et al., 2021; Taylor & Baek, 2018). Aggarwal (2011) highlighted the role of skills development among students but did not specify how these skills will be developed. In various other studies, the role of instructors in introducing interventions like robotics, small codes, programming in blocks, assigning group-based tasks, and collaborative thinking proves to be fruitful in enhancing the vision and cognitive skills of the students (Acar et al., 2018; Cannon-Ruffo, 2020; Reich-Stiebert et al., 2020; Zhang et al., 2021). Therefore, educational designers must consider skill development from a technological perspective to strengthen the STEM field and prepare students for their scientific and engineering careers.

Chapter Summary

The literature showed the effectiveness of the implementation of ER in academic settings with observable outcomes such as behavioral improvement, STEM educational attainment, cognitive development, teamwork and collaboration, language development, syntactic skills, problem-solving, and many more (Arfé et al., 2020; Chevalier et al., 2020; Durak et al., 2019; Julià & Antolí, 2016). However, implementing ER-based education and programming for young children in academic settings has challenges. The cost of implementing ER-based education is a significant hurdle for developing countries, especially in rural areas where basic facilities for education are scarce. There is also a need to design an ER framework that dynamically evaluates and assesses the requirements of students for learning different subjects, including STEM. This domain requires further research as most researchers focus on the short-term implementation of robotics and programming in education. Enhancing the students' vision in different aspects of business, programming, or coding-based education could prove to be a fruitful tool in the modern era (Aggarwal, 2011). The global movement toward digitalization will increase the need for learning programming and CT (Da Cruz Alves et al., 2019). One of the essential competencies of CT is programming without a predefined solution by using basic building blocks of basic codes through visual tools (Da Cruz Alves et al., 2019).

Chapter 3: Research Method

CT is a process (Tsai et al., 2019) that uses data structures, iterations, and algorithms to construct a relevant solution based on systematic analysis (Bers & Sullivan, 2019). The development of CT skills is necessary to thrive in the current digital age, as computers are increasingly used in problem-solving. The lack of CT skills can impede K–12 students from maximizing their academic potential, creating warranted concerns for educational leaders (Ching et al., 2018). The purpose of this qualitative descriptive study was to understand the role of ER in elementary-aged students in developing CT skills through analysis of elementary robotics instructors' experiences and observations. This chapter includes the methodology, rationale for the research design, population, sampling method, instruments, and data collection and analysis procedures. Lastly, this chapter established confidence in the research findings by discussing the assumptions, limitations, delimitations, and ethical considerations to authenticate the current study's findings.

Methodology

The current qualitative study was based on Papert's (1980) constructionism theory. Papert's central idea of constructionism is an "object-to-think-with." The ER hardware and software platforms are designed for elementary-aged children and do not require previous experience. As students built their knowledge and skill sets in robotics, instructors introduced a challenging curriculum that promoted discovery experiences. The qualitative descriptive research method analyzed instructors' perspectives on how elementary students develop CT skills through ventures with ER. This research sought to identify patterns and build connections by interpreting instructors' lesson plans, instructors' observations, and student work. The research provides evidence for the relationship between CT and robots in hands-on classroom activities to encourage an option for 21st-century educators to enhance student achievement in the education system.

ER is an ideal constructionist tool for developing CT concepts of decomposition, abstraction, pattern recognition, and algorithmic designs. Bers and Sullivan (2019) contended that consistent participation in CT exercises strengthens students' likelihood of transferring critical thinking skills to other disciplines. Seiter and Foreman (2013) defined CT concepts as sequencing, loops, conditional, incremental, iterative, testing and debugging, abstracting and modularizing, and algorithms.

In this study, robotics instructors selected lessons and student work products accompanied by surveys completed by the instructors to illustrate the development of CT. Additionally, instructors participated in qualitative interviews to address the following research questions:

RQ1. How do instructors describe the use of educational robotics to promote critical thinking skills among elementary students?

RQ2. What are instructors' perspectives on the development of computational thinking using educational robotics?

Research Design and Method

The research was evaluated as a descriptive qualitative study to summarize the perceptions of elementary school robotics instructors. Deductive thematic analysis was used because the data has a predetermined set of themes (Braun & Clarke, 2006; Merriam & Tisdell, 2016). Qualitative research encourages full transparency from participants (Leavy, 2017). Respondents expressed a deeper interpretation of their understanding, which can be challenging with a closed-ended survey (Saldana & Omasta, 2018).

The research analysis identified and categorized the collected data using the predefined themes. The themes were used to build an understanding of the data. The deductive thematic analysis was most appropriate because prior research provided the framework for the analysis. Participants provided information based on their observations of students participating in the ER program in an elementary school setting. Programs varied from formal instruction during a scheduled class to informal instruction in an after-school robotics program. The data collection included instructor lesson plans, student work products accompanied by a survey completed by the instructor, and semistructured interviews.

Additionally, a qualitative inquiry through a constructivist paradigm was applied because I sought to investigate experiences of elementary ER programs and how these experiences were interpreted (Glesne, 2016; Leavy, 2017). Because the focus was on analyzing instructors' perspectives of robotics activities, a constructivist-styled methodology was selected over other methods. The goal was to discover any patterns or resemblances among the group participants. Additionally, a narrative approach was carefully chosen over other methods because the focus of the study was to gain a descriptive comprehension of a particular phenomenon through the lenses of individual research participants (Mills & Gay, 2016). When participants shared their experiences in elementary ER programs, they provided comprehension of how each participant creates the meaning of the robotics phenomenon.

According to Papavlasopoulou et al. (2020), "Constructionism assumes that knowledge is better gained when children are deeply and actively involved in building their meaningful construction" (p. 416). The theory concluded that children would build from previous knowledge when designing a project. Papert (1980) contended that discovery will build new competencies rather than receiving them passively, enabling participants to encounter a more significant learning experience.

Setting

This research was situated in Texas, not at a specific school or district, studying the experiences of research participants who teach ER to elementary students. The participants from this study were recruited through posting on social media groups for ER teachers and snowball sampling. The Lego® Education Mindstorm® community and VEX IQ worldwide coaches are private Facebook groups with over 20,000 and 2,500 members concurrently. The group members were ER enthusiasts that included but were not limited to teachers, administrators, mentors, coaches, and parents.

Population and Sampling

This qualitative study described the observations and experiences of instructors who provide formal and informal instruction in ER with elementary students in Texas. Instructors included but were not limited to individuals holding a teacher's certificate, STEM professionals providing instruction and mentorship for a robotics program or team, and undergraduate college students studying in a STEM field who choose to mentor or teach robotics within a community. The study participants were required to meet the following criteria: (a) above the age of 18 and (b) provide formal or informal robotics instruction to elementary school students in Texas. The participants did not need to be certified teachers but were required to be trained with a working knowledge of ER.

Purposive sampling was used to identify specific participant selection criteria (Leavy, 2017; Mills & Gay, 2016). Because the research required a specific phenomenon or experience, the focused sampling enabled an opportunity to gather relevant data (Creswell, 2015; Patton, 2015). Qualitative studies have small sample sizes. Mason (2010) stated that qualitative studies are designed with the understanding or meaning of the topic as the goal, not proof of a hypothesis. Guetterman (2015) concluded, “Sampling is not a matter of representative opinions, but a matter of information richness” (p. 391).

I recruited participants via social media (see Appendix A) and used the snowballing method. As a member of the Lego® Education Community on Facebook, I posted a link to a Google document for elementary school robotics instructors interested in participating in the descriptive qualitative study of ER and the development of CT. The Google document included questions to qualify the potential participants and an explanation of the study (see Appendix B). Recruitment also included asking instructors who met the criteria to participate in the study and further asking for referral of qualified participants. The first 10 instructors who replied were selected for an interview with the intent to meet data saturation. Instructors who chose to participate received a consent form via email with full disclosure of the study and the opportunity to opt-out. There were no consequences for those who chose to opt-out.

Materials and Instruments

The participants also submitted a document with their observations of student work that illustrated CT skills. The student work product demonstrated learning of the submitted lesson outline. Participants provided a written account of their observations of student work. The survey questions can be found in Appendix C.

Participants were asked questions from a semistructured interview protocol (see Appendix D) to collect data to understand the in-depth experience of teaching elementary students using robotics education platforms. The protocol included observations of student’s learning from the submitted lesson. The semistructured interviews were structured with simple questions to provide relevant indicators to reduce respondents' chances of losing interest (Kaufman & Guerra-Lopez, 2013). The open-ended questions allowed the participants to provide detailed responses as they shared their experiences (Leavy, 2017; Mills & Gay, 2016).

The interview questions (see Appendix D) and surveys (see Appendix C) were developed based on literature (Munn, 2021) and my personal experience as a robotics instructor. The quality of research findings improved when I solicited support from career professionals (Anney, 2014). The research, which includes processes for data collection, analysis, and interpretations, was enhanced by critiques from the dissertation committee and colleagues (Mertler, 2017).

Peer debriefing also provided insight from professionals' intuitive experiences. This process improved the reliability of the data collection instrument and ensured that the questions were easily understandable and provided the anticipated information from the interview. I field-tested the questions by interviewing two colleagues who previously taught elementary robotics to ensure that the interview and survey questions were ethical, conversational, and participant-centered with research alignment. These interviews were not included in the study's data collection. Based on the peer feedback, the questions were revised by combining questions that would yield similar responses and omitting irrelevant questions that would not provide insight for answering the research questions.

Data Collection

Qualitative data was collected through lesson plans, student work products, and semistructured interviews to discover the participants' overall experiences teaching robotics activities to elementary students to develop CT skills. Perceptions of stakeholders provided the data for this study. Qualitative research encouraged full transparency from participants (Leavy, 2017). Respondents expressed a deeper interpretation of their understanding, which can be challenging with a closed-ended survey (Saldana & Omasta, 2018). Artifacts used for data collection included instructor lesson plans, student work with detailed instructor observations, and semistructured interviews.

A technique used to ensure the reliability of the research is triangulation. Each data source uses different methods to collect and analyze data. Triangulation is reviewing data collected through different methods for increased accuracy and valid conclusions of the results (Allen & Oliver-Hoy, 2006). Patton (2015) explained, “Triangulation, in whatever form, increases credibility and quality by countering the concern (or accusation) that a study’s findings are simply an artifact of a single method, a source, or a single investigator’s blinders” (p. 563). The use of multiple sources was a strategy to reduce bias and increase validity and study credibility (Anney, 2014; Merriam & Tisdell, 2016). When researchers can verify numerous data sets against each other, the findings are more likely to be trustworthy (Carlson, 2010; Mertler, 2017).

The current study used multiple data collection methods for triangulation (Herr & Anderson, 2015; Saldana & Omasta, 2018), including students’ work products, participants’ lesson plans, and a semistructured interview of the elementary robotics instructor participants. During the data collection, I discussed the findings with other professional peers to examine the data for the accuracy of the results. This research employed the benefit of member checking as the participants were asked to read the transcripts and interpretations to ensure accuracy.

Three types of data allowed the triangulation of sources. First, participants provided an example of the lesson outlines used for the ER sessions. The lesson outlines could have been original drafts or curricula designed by the instructional team of the designated robotic platform.

The lesson plans included the objective or challenge and the method used to model examples to support the student's comprehension.

The second source of data was student's work products. Instructors selected a student product representing the submitted lesson outline that illustrates CT. The student work included a copy of a paper or electronic journal and design plans or drawings and pictures of the robots that students designed. The instructor provided a written discussion discussing how the work product demonstrated the principles of CT (see Appendix C). The survey of student work was then coded based on the CT codes (see Table 1).

Table 1

Computational Thinking Codes

Code	Explanation
1. Sequences	A series of individual steps or instructions.
2. Loops	Repetition of the action.
3. Parallelism	Sequences of instructions happening at the same time.
4. Events	One thing causes another to happen.
5. Conditionals	Making decisions based on certain conditions.
6. Being incremental and iterative	Cycles of imagining and building.
7. Testing and debugging	Trial and error, transfer from other activities, or support from knowledgeable others.
8. Reusing and remixing	Building on other people's work.
9. Abstracting and modularizing	Building something significant by assembling collections of smaller parts.
10. Boolean expression	Using terms like 'AND 'OR' to sort data appropriately.
11. Procedures and algorithms	Step-by-step, exact instructions.
12. Program decomposition	Taking a significant problem and breaking it into smaller, more manageable steps.

13. Collecting data	Through observation and measurement, gathering and recording various data.
14. Creating data (representing)	Using simulators to create data they can use to investigate the topic at hand.
15. Manipulating data	Manipulating and reshaping data sets so that they can be helpful moving forward.
16. Analyzing data	Making claims and identifying trends/correlations/patterns/anomalies.
17. Visualizing data	Creating visualizations to communicate data. Graphs, charts, interactive displays.
18. Using computational models to understand a concept	Using flowcharts, diagrams, equations, and even physical models.
19. Using computational models to evaluate solutions	Test solutions quickly without committing to a specific approach.
20. Assessing computational models	Articulate similarities and differences between the model and real life.
21. Designing computational models	Defining the model's components, explaining the assumptions.
22. Constructing computational models	Encoding model features in a way a computer could interpret.
23. Preparing problems for computational solutions	Mapping problems onto the capabilities of the tools. Reframing problems into forms that can be solved.
24. Choosing practical computational tools	Identifying strengths and weaknesses of specific tools, choosing the most effective ones (weighing pros and cons).
25. Assessing different approaches to a solution	Assess options and choose which route to follow.
26. Pattern recognition	Ability to recognize a pattern.

Note. From "Noticing and Naming Computational Thinking During Play," by D. Kotsopoulos, L. Floyd, B. A. Dickson, V. Nelson, and S. Makosz, 2021, *Early Childhood Education Journal, 50*, p. 704 (https://link.springer.com/article/10.1007/s10643-021-01188-z). Reprinted with permission.

I also used instructor interviews as this study’s third data collection method. The methodological purpose of interviews was to provide data that can be examined, offering insight into the “inner contents of peoples’ minds and authentic selves” (Roulston & Choi, 2018, p. 234). There were several interview techniques, such as hermeneutic, ethnographic, and feminist, which were variables of the interview itself, with consideration of the methodological and theoretical basis of the qualitative study. However, this study used the generic interview protocol, which focused on the participants’ experiences and observations and “the meanings they ascribe to those experiences so that the researcher could describe those experiences and generate generalizable understandings” (Roulston & Choi, 2018, p. 235). This method was chosen because it allowed participants to elaborate using guided questions with unrestricted responses (Mills & Gay, 2016). Ideally, the interviews felt like a conversation between the participant and myself, enabling me to explore the participant’s experience more deeply (Ezzy, 2010).

Interviews were conducted via Zoom. The discussions were 15–30 minutes. The recordings were transcribed (Locke et al., 2010) to preserve the responses for the coding and analysis of the documented stories. Recorded interviews were deleted within 30 days after the interview. Lastly, study participants were reassured that their identity and responses would be kept confidential, that no personal information would be disclosed, and that pseudonyms would be used.

Measures were taken to ensure rigor and trustworthiness within the research. In action research, rigor was achieved through procedures that ensure unbiased results (Stringer, 2007). Trustworthiness was established through accurate and believable data (Mertler, 2017). The study used triangulation, member checking, thick, detailed descriptions, and peer debriefing to ensure rigor and trustworthiness.

Data Analysis

I forwarded the interview transcripts to participants to review for clarity and feedback. Through member checking, participants certified the accuracy of the conclusions from the research in which they shared their experiences (Doyle, 2007). Participants reviewed and polished the interview transcripts and the concluded inductive analysis. The participants' review ensured the interpretations' accuracy and allowed participants to contribute additional thoughts. When member checking was concluded, the necessary revisions from participants were made to ensure the accuracy of the transcripts and conclusions drawn.

The interviews were coded (Creswell & Creswell, 2017). The data was analyzed for developing themes. All narratives were analyzed and interpreted through a humanistic and holistic approach that combined the participants' stories, the context, and my own experiences gained while teaching ER in elementary school programs (Wolcott, 2009).

This phase established the study's validity, which relied on determining the study's trustworthiness, transferability, and dependability to assess whether the data accurately reflected what the research was trying to measure (Mills & Gay, 2016). This study applied Guba's (1981) criteria for assessing the trustworthiness of naturalistic inquiries by establishing corroboration and coherency by comparing the participants' responses to identify if there were any contradictory experiences among them and identify any possible bias (Mills & Gay, 2016).

The research used deductive thematic analysis because the study focused on looking for specific patterns or themes of CT (Saldana & Omasta, 2018). The predetermined categories for labeling were used for the lesson plans, the interviews, and the student work samples. I began by identifying relevant themes and issues and then used the categories to systematically analyze the collected data (Saldana & Omasta, 2018). Responses were coded and evaluated for cross-referencing CT processes (Locke et al., 2010). I did not use conventional or summative content analysis because, unlike directed content analysis, conventional and summative content analysis does not begin with predetermined categories or codes. Conventional and summative analysis requires the researcher to develop a set of categories or codes based on the theme that emerges to provide a detailed and comprehensive description of the study content.

The data was examined for evidence of CT codes as identified by Kotsopoulos et al. (2021, p. 704; see Table 1). The study was granted authorization to reproduce the computational codes for research purposes. The coded text was compared and analyzed for patterns and frequency of ideas. The data provided insight into students' computational processing and the benefits of using ER to enhance these skills (see Table 1).

The research provided detailed descriptions of settings, participants, data collection, and analysis procedures to ensure credibility (Anfara et al., 2002). Creswell and Miller (2000) concluded that an additional purpose for thick, detailed descriptions is to help draw the reader closer to the occurrence, creating a sense of connection with the study's participants. The broad, rich imagery lets the reader decide if the findings "ring true" (Shenton, 2004, p. 69).

Ethical Considerations

I addressed ethical considerations for the entirety of this research. The study participants were robotics instructors in Texas. Data collection was interpretations of robotics instructors' observations and experiences. Standard informed consent was issued to participants after institutional review board (IRB) approval. The consent form explained the nature of the study, participants' rights, and assurance that participants would remain anonymous. The participant returned a signed copy of the consent to participate in the research via Dropbox. No personal identifier and school or district identifiers were included in the data collection or shared in the results.

This qualitative study ensured trustworthiness throughout the data collection process. The interview process was conducted with an awareness to avoid leading questions; instead, the identified and follow-up questions were topic-clarifying (Marshall & Rossman, 2016; Maxwell, 2012). While natural dialoging occurred during the interview, it was essential to document the conversation. Trustworthiness also requires being as factual and nonbiased as possible when documenting observations, discussions, and examining transcripts (Holland & Leander, 2004). I documented the study by keeping a journal. I also used detailed notes when reviewing transcripts, which navigated the discovery of emerging themes. I built other trustworthiness by not focusing on individual student variations or overidentifying with themes from the narratives (Holland & Leander, 2004; Marshall & Rossman, 2016; Maxwell, 2012).

Researcher's Role

I am currently an elementary robotics instructor with 10 years of experience. While I positively utilized prior experiences to drive the study, the data collection reflected the essence of the experience from the participants' perspectives. My position in this study was to interview and transcribe data collected from the participants. One limitation was I was the primary receiver of the data. To ensure accuracy, I transcribed exact data, paying careful attention not to prejudice or bias the collected data (Creswell, 2015). The interview format was semistructured using open-ended questions, allowing the participants' perspectives to direct the data collected for this qualitative study.

Assumptions

Assumptions of qualitative research inform readers of the basis for choices regarding preconceptions and beliefs about the research paradigm. By explicitly discussing the assumptions, the readers can be assured that the research involved thoughtful and rigorous consideration (Caelli et al., 2003). The first assumption of this study was that potential participants would answer the interview questions honestly. It was also assumed that the instructor implemented the ER and programming platform effectively.

Limitations

Limitations imposed constraints I could not control, hindering the potential to generalize outcomes (Terrell, 2016). The nature of the qualitative study had inherent limitations. The first limitation was linked to the semistructured interview method. Interviews in this qualitative research aimed to uncover the truth experienced by informed robotics instructors while offering participants a chance to voice their insights when such opportunities might not have been available (Atkinson & Silverman, 1997, p. 311).

Transferring the findings and conclusions from this study was a research limitation. Even though this study aimed to grasp insights through instructors' viewpoints and experiences, outcomes were constrained to instructor views and might not represent other stakeholders tied to ER. Nevertheless, the objective of this research was to comprehend the significance of ER in fostering CT among elementary school students.

Delimitations

Bloomberg and Volpe (2008) argued that there should have been limits to qualitative research to ensure it remained centered on the research question. Establishing such boundaries facilitated the reproducibility of the study by integrating controls that filtered out unrelated data outcomes (Terrell, 2016). This investigation aimed to examine the influence of ER on fostering CT among elementary students. Instructors specializing in elementary ER, when contrasted with broader elementary educators, formed a niche group. As a result, it was anticipated that attracting a significant number of these specialized instructors for participation might have posed a challenge. The research intended to delve into the experiences of ER instructors who taught mainstream elementary students who possessed minimal to no background in the subject. Any nonpertinent data from participants was not factored into the findings.

Trustworthiness

Trustworthiness was established through accurate and believable data (Mertler, 2017). It was essential that inferences in scientific research accurately reflected the data obtained and represented the scope and depth of the subject that was researched. Qualitative research met this criterion when there was an explanation with trustworthiness and authenticity. Establishing trustworthiness in qualitative research required the audience to be convinced that the data was accurate, feasible, consistent, and impartial. Lincoln and Guba (1985) contended that the principles for establishing qualitative research trustworthiness included credibility, transferability, dependability, and objectivity. This study used triangulation, member checking, and detailed descriptions to ensure trustworthiness.

Credibility

Credibility was expressed as the coherence between the research findings and reality. It was related to the trust in the accuracy of the results obtained from the research participants, the sources of information, and the research context (Lincoln & Guba, 1985). Lincoln and Guba (1985) suggested that triangulation, peer examination, and member checking would increase reliability within the scope of this research. The research design was based on elementary robotics teachers' lesson plans, student work samples, and teacher interviews. I observed and translated the participants' perspectives within the scope of the study. The interviews with the participants provided an in-depth insight into their educational beliefs and pedagogical field knowledge.

Transferability

Transferability (adaptability) required that the findings and results were generalized to similar circumstances and events (Lincoln & Guba, 1985). I was responsible for explaining the research-related properties of the context that was studied to ensure adaptability (Shenton, 2004). In this manner, those who read the research were able to generalize to similar situations. The proposed study was described in detail to ensure transferability (Lincoln & Guba, 1985). The research explained the study's content and process, the selection of participants, the context in which the investigation had been conducted, and the data collection process.

Dependability

Dependability arises when data aligns consistently with the findings (Merriam, 1998). This research employed Guba's (1981) standards to assess the reliability of naturalistic studies, ensuring corroboration and coherence by examining participants' feedback for any inconsistencies or potential biases (Mills & Gay, 2016). Within qualitative research, dependability does not necessitate replicating identical results by another researcher using the same data. Rather, conclusions should be drawn logically from the data at hand (Pitney, 2004). To guarantee research dependability, comprehensive details about the setting, methodology, and data collection process are recommended (Cobb & Gravemeijer, 2014; Shenton, 2004). This research ensured reliable data collection and analysis techniques, presenting findings in a manner that other researchers can comprehend and replicate.

Confirmability

Confirmability, or neutrality, pertains to the researcher's impartiality. A study's results should mirror participants' experiences and perspectives, uninfluenced by the researcher's personal biases or attributes. The researcher maintains accuracy in presenting findings by including direct quotes from participants gathered during interviews and observations (Yin, 2003). Confirmability was reinforced through neutral data handling, triangulation, in-depth descriptions of data tools, and data analysis (Shenton, 2004). This research underscored confirmability by detailing each step and rationale for decisions made throughout the study.

Chapter Summary

This chapter detailed the methodology applied to address the research questions.

RQ1. How do instructors describe the use of educational robotics to promote critical thinking skills among elementary students?

RQ2. What are instructors' perspectives on the development of computational thinking using educational robotics?

The primary aim of this research was to offer educational leaders comprehensive data to contemplate incorporating and broadening the use of ER in their curricula. In this qualitative descriptive analysis, a narrative approach was used to scrutinize the lesson plans, observations of student work, and semistructured interviews of robotics instructors. The objective was to understand their experiences while teaching robotics programs to young elementary students. Data collection was executed through a purposive sampling technique, gathering insights into the instructors' views on children's engagement with ER.

Resnick et al. (2009) championed the core concept of constructionism, which emphasizes learning through action. Numerous scholars have leveraged this principle when integrating robotics and coding activities, aiming to enhance skills like coding, problem-solving, critical thinking, and collaboration (Papavlasopoulou et al., 2020). ER offer students a means to develop higher-order thinking by visualizing multifaceted issues across various fields and breaking them down into manageable chunks (Aggarwal, 2011; Chevalier et al., 2020). The purpose of this research was to delve deeper into the influence of ER on nurturing CT among elementary pupils. Opting for a qualitative descriptive method was appropriate for the research questions, as it aimed to understand participants' experiences (Creswell, 2014). It shed light on the role of ER in fostering CT capabilities among young learners.

Furthermore, this research delved into the perceptions of robotics instructors regarding the influence of CT approaches within ER activities. The study's theoretical foundation encompassed the impact of ER on CT, an assessment of its merits, demerits, and challenges, and the potential of educational robots to enhance productivity. Again, the qualitative method was chosen for its suitability in exploring participants' viewpoints (Creswell, 2014). The rigor of this research adheres to the six standards essential for qualitative research: reflexivity, methodological consistency, sampling and data collection considerations, validation of data through member checks, discussions about applicability, and ethical considerations (Anderson, 2017).

Ideally, this research offered educators valuable insights for crafting ER activities aimed at enhancing computational skills. As Wing (2011) noted, computational skills are universally beneficial, not restricted to computer scientists alone. Hence, introducing CT abilities at the elementary level can be highly advantageous for students. This research furnishes insights into the role of ER in cultivating CT among elementary school students.

Chapter 4: Results

The purpose of this qualitative descriptive study was to understand the role of ER in elementary-aged students in developing CT skills through analysis of elementary robotics instructors' experiences and observations. The study sought to explore instructors' perspectives on the impact of teaching ER, identify CT patterns, and provide insight into the design of robotics activities to contribute to student achievement in CT in the educational landscape. The plan was to use deductive analysis with a framework, but in looking at my data, the themes emerged more inductively. The emerging codes aligned with literature and these codes were collapsed to define themes. In the course of this research, robotics instructors chose specific lessons and filled out a survey concerning student assignments to showcase the progression of CT. Additionally, instructors participated in semistructured interviews to address the following research questions:

RQ1. How do instructors describe the use of educational robotics to promote critical thinking skills among elementary students?

RQ2. What are instructors' perspectives on the development of computational thinking using educational robotics?

Participants

The study examined teacher interpretations and experiences using Lego® EV3 and VEX IQ ER platforms. The robotics platform was used in elementary classrooms and after-school programs like robotics and science clubs. I intended to recruit through Facebook but struggled to identify participants. I contacted colleagues and asked elementary robotics instructors to volunteer and suggest other potential participants.

Upon expressing interest in participating in the study, I requested the instructor's email address to forward a link to a Google document. This document contained a letter detailing the study (see Appendix E). At the end of this letter, there was a link to a Google form to prequalify potential participants and gather their names and email addresses (see Appendix B). The study participants were required to meet the following criteria: (a) above the age of 18 and (b) provide formal or informal robotics instruction to elementary students in Texas. While a teaching certification was not mandatory, participants must be trained with a working knowledge of ER.

The original number of participant volunteers was 10, but one instructor failed to submit the student work that included observations, and the second instructor was not available for the interview. The incomplete data from both instructors was deleted and not included in the study; therefore, the total number of participants was eight. The participant profiles are shown in Table 2.

Table 2

Participant Profiles Based on Selected Criteria

Participant's pseudonym	Education	Formal or informal instructions	Educational robotics experience
Chris	College Sophomore Engineering	Informal after-school instructions	5 years Started Robotics in high school
Eric	College Senior Mechanical Engineering	Informal after-school instructions	11 years Started Robotics in elementary school
Sandra	Master's in Science	Certified teacher informational instruction	3 years
Shawn	Doctorate in Education	Certified formal instruction	2 years
Sheila	Doctorate in Cyber Security	Certified teacher informal instruction	5 years
Steve	College Junior Civil Engineering	Informal after-school instructions	6 years Started Robotics in high school
Terry	Master's in Education	Certified teacher formal instruction	4 years
Vince	Bachelor's of Science in Biology	Certified teacher formal instruction	12 years

After the participants were prequalified and completed the informed consent, the data collection began. The data included teacher's lesson plans, teachers' survey questions as a narrative of students' work (see Appendix C), and teacher interviews (see Appendix D). Each participant uploaded their lesson plans, student work, and their survey questions as a narrative of students' work (see Appendix C) to a Google folder. Additionally, I added the teacher interview questions (see Appendix D) for informational purposes. The teacher interviews took place through recorded Zoom sessions, and the information was transcribed word for word to ensure its accuracy. I thoroughly reviewed the material by repeatedly reading the transcriptions and listening to the audio recordings. The data collection process concluded with member checking.

Member checking, also known as participant validation, was used to enhance the data's accuracy, credibility, and validity (Creswell, 2013). The teacher interview transcript and coded themes were shared with the participants to review my interpretations as the researcher. After receiving participant feedback, I made minor adjustments to confirm accuracy. The feedback included corrections for spelling errors in the transcription. The participants concurred with the thematic coding, and no further coding was required. This process ensured that the findings were consistent with the participants' intended meanings and experiences.

Table 1 showcases the CT codes pinpointed by Kotsopoulos et al. (2021, p. 704). I emailed the author and received permission to use the same codes. In this research, codes with similar meanings or patterns were examined, merged, and organized into themes. The essence of developing themes was to capture a central idea or concept that emerges using a broader title. Finally, the data were interpreted to connect the findings to the research questions initiated in this study. The findings were written using paraphrases and quote extracts from the data to support and illustrate the themes and provide a coherent narrative about the participants' experiences. The themes (see Table 3) included programming concepts, problem-solving and design, abstractions and modularization, data management and analysis, and computational modeling.

Table 3

Thematic Codes

Theme	Computational thinking codes
Programming Concepts	• Sequences: Basic programming structures and the order of operations. • Loops: Techniques for repeating specific actions. • Parallelism: Managing multiple tasks simultaneously. • Events: Triggered actions based on specific occurrences. • Conditionals: Decision-making in programming. • Boolean expression: Logic-based decision criteria. •
Problem-Solving & Design	• Being incremental and iterative: The iterative process of design, prototype, test, and redesign. • Testing and debugging: Identifying and resolving issues. • Problem decomposition: Breaking down more significant problems. • Preparing problems for computational solutions: Adjusting or reframing issues to be more computationally approachable. • Choosing practical computational tools: Deciding on the best tools for the task. • Assessing different approaches to a solution: Comparing and selecting from multiple solution paths. • Pattern recognition: Identifying repeating or underlying structures. •
Abstraction & Modularization	• Reusing and remixing: Incorporating existing solutions or modules. • Abstracting and modularizing: Grouping functionality into manageable and reusable chunks. • Procedures and algorithms: Developing structured solution pathways. •
Data Management & Analysis	• Collecting data: Gathering raw data from various sources. • Creating data (representing): Simulating or developing new datasets. Manipulating data: Adjusting, cleaning, or transforming data. • Analyzing data: Interpreting data to find insights or patterns. • Visualizing data: Creating graphical representations of data for better understanding. •

Theme	Computational thinking codes
Computational Modeling	• Using computational models to understand concepts: Utilizing models as teaching and understanding tools. • Using computational models to evaluate solutions: • Testing potential solutions via simulations and assessing computational models: Comparing and contrasting models to real-world scenarios. • Designing computational models: Conceptualizing and structuring new models.

Thematic Codes

Thematic coding is a qualitative research method used to identify, analyze, and report patterns or themes within data (Anderson, 2017). At its core, it involves examining data closely to determine the recurrent and significant ideas or concepts. Creating relevant themes allows researchers to organize and describe the dataset in rich detail (Guetterman, 2015). I developed themes by categorizing data into similar codes. Sequencing, loops, parallelism, events, conditions, and Boolean expressions were all grouped under the “programming concepts” theme because they all pertain directly to the construction flow and logic of written code (Moraiti et al., 2022). They are fundamental tools and paradigms that programmers use to dictate how a computer should process information and react to inputs. Each of these concepts contributes to the essence of programming.

The “problem-solving” theme revolves around the processes and strategies used to approach, understand, and solve problems, particularly regarding programming and CT. Addressing and resolving challenges involves a series of steps, including gradual progression, repeated testing and refining, breaking down problems, setting up problems for computational resolutions, selecting appropriate computations, evaluating various solution strategies, and recognizing patterns (Moraiti et al., 2022). These codes provide a structured approach to understanding the nature of the problem, devising strategies, implementing solutions, and refining those solutions. Collectively, they define a comprehensive approach to facing a challenge, especially in a computational context.

Reusing and remixing, abstracting, and modularizing procedures and algorithms are placed in the theme of “abstraction and modularization.” The theme’s essence revolves around the idea of simplifying complex systems into comprehensible, reusable components (Çinar & Tüzün, 2021). Grouping these computational codes under the same theme is appropriate and coherent because each embodies this idea.

“Data management and analysis” are the sequential connected steps to derive insight from raw data (Sisman et al., 2022). Collecting, creating, manipulating, analyzing, and visualizing data represent statistical details from initial collection to the final presentation. Each step is critical in ensuring the data serves its purpose: informing decisions, supporting research, or driving innovation.

Using computational models to understand a concept, using computational models to evaluate solutions, assessing computational models, designing computational models, and constructing computational models revolve around using, creating, and assessing computational models (Jamal et al., 2021). These tasks are integral to the computational modeling process from conception to evaluation. Grouping them under the “computational modeling” theme emphasizes their linkage in leveraging computational tools to represent, explore, and understand complex systems.

Analysis of Data Sources 1: Lesson Plans

The subsequent section provides a concise overview of the lesson plans incorporated within this study, emphasizing their relevant features, objectives, and pedagogical methodologies employed. These lesson plans represent diverse educational settings and serve as pivotal reference points in the exploration and analysis throughout the study. It is imperative to note that to uphold the highest standards of research ethics and ensure the confidentiality of all involved, pseudonyms have been utilized in lieu of real names or identifiable markers. This measure ensures the anonymity of the subjects and institutions, thereby preserving their privacy and the integrity of this research.

Summary of the Eight Lesson Plans

Chris's (pseudonym) lesson plan focuses on introducing VEX IQ sensors and their applications to students. The lesson begins with helping students understand the logical functions of blocks, such as cause and effect in if/then statements and input/output in sensing blocks. Students then face the challenge of thinking creatively to design automated functions their robots can perform using sensors. They finalize their program with the VEX IQ coding app. A key emphasis is on learning through trial and error. The lesson also introduces valuable programming skills in steps, making it easier to troubleshoot issues. The critical terminology highlighted is "debugging."

Eric's (pseudonym) class revolves around designing and constructing a VEX bat bot. The lesson offers students the flexibility of either innovating their designs or reverse engineering existing examples. The main activity includes the construction phase, characterized by trial and error, followed by the manual or autonomous robot control decision-making process. As an extension, students are encouraged to think outside the box to customize their robots and add new mechanisms. Key concepts introduced included "structural integrity," "speed," and "torque."

Sandra’s (pseudonym) plan teaches students to use the EV3’s switch block for sensor-based decisions. After building specified modules, students watch a video detailing program control before testing a sample program. They are encouraged to adjust block parameters to optimize robot behavior. If the robot does not follow a given line correctly, students must adapt sensor thresholds by measuring light levels and calculating an average for optimal robot performance.

Shawn’s (pseudonym) lesson caters to grades 3–5, introducing students to VEX IQ robotics and its components. The class begins with discussing robot parts, emphasizing their connection and individual roles. The build phase encourages students to use VEX IQ Super Kits and Robot Base instructions to assemble a foundational robot. Once completed, students test their robots’ functionality, learning how to troubleshoot issues and understand the mechanics of code transmission. A reflection session prompts students to consider alternative designs and improvements for their current models.

Sheila’s (pseudonym) lesson plan revolves around gears and ratios, designed for students to gain hands-on experience with the VEX IQ super kit. Students construct a gear ratio simulator and address challenges emphasizing the alteration of speed and torque using combinations of driven, driving, and idle gears. Through these activities, students master the basics of gear ratios and the identification and application of simple machines. Students also apply their new knowledge to practical scenarios, demonstrating its relevance to real-world robotics applications. The lesson has an iterative challenge approach, where students progressively tackle new challenges after mastering previous ones. This scaffolded learning style promotes comprehension and ensures that students fully grasp each concept before moving on.

Steve’s (pseudonym) lesson invites students to navigate their robot through a maze using autonomous coding. Students first get an overview of the competitive landscape of VEX IQ robotics, understanding the significance of both autonomous and manual robot control. Using the VEXcode IQ app, students learn the basics of creating a project and utilizing drivetrain blocks. The lesson emphasizes the distinction between primary and complex movement commands. The hands-on experience enables students to understand and apply coding concepts to navigate robots autonomously.

Terry’s (pseudonym) lesson plan focuses on building the VEX Clawbot, incorporating its electrical wiring, and testing the constructed robot using a joystick remote. After a team discussion to create a plan for completion, students follow instructions to finish the building. The extension task is based around a NASA robot and building a suitable robot for the terrain of Mars. The extension activity offers a potential connection to geography.

Vince’s (pseudonym) lesson aims to teach students about connector pieces and the dynamics of gearing robots for increased speed. Students are introduced to Lego® connector pieces and fundamental formulas like calculating speed and wheel circumference. The lesson emphasizes the relationship between speed, torque, and significant gear ratios. Students engage in hands-on activities where they gear up their robots, race them, and apply mathematical concepts to calculate speeds and potential distances traveled. The lesson includes homework that reinforces the speed = distance / time formula.

Lesson Plan Trends

Examining the lesson plans in the context of ER and CT provides insight into some recurring patterns regarding learning objectives and activities, cognitive skills, reflection and iteration, real-world application, vocabulary, and concept understanding. The lesson plans submitted for the study were very diverse in format and content. While the goal was to examine CT, other observations, not specifically CT themes, were worthy of discussion. The mention of additional observations added clarity to the introduction of the lesson plan data.

Each lesson plan started with a clear learning objective that outlined the specific skills and concepts students are expected to acquire. The objectives included learning about specific components, understanding gear ratios, building a robot, and programming with control units. Vince's gearing lesson said, "Objective: 1. Students will learn about connector pieces. 2. Students will learn how to gear up their robots for increased speed. They will run their robots and calculate the average speed using the formula, speed = distance / time." Steve's lesson plan concluded, "In this activity, students will learn to write code for their robot to autonomously navigate a maze." Sheila's lesson plan communicated:

> Learning Objectives: Campers will become familiar with the basic building components of the VEX IQ Super Kit. Campers will use appropriate terminology to describe basic VEX IQ building components. Campers will learn about and apply basic knowledge of Gear Ratio (Gear Train, Driving Gear, Driven Gear, Idler Gear, and Gear Ratio). Campers will be able to identify different kinds of simple machines visually. Campers will document their machine and its use.

Shawn listed her learning goals as follows, "To introduce students to VEX IQ robotics; to teach students about robot parts; and for students to build an easy starter robot." Terri's lesson objectives articulated, "Students will complete the construction of the VEX Clawbot using the instructions manual provided. When completed, they should use the control unit and joystick to test their robot."

All the instructors in the study emphasized hands-on learning and experimental activities as central to their lesson plans. The lessons indicated that students were provided with the material and were guided through designing, constructing, and programming a robot using step-by-step instructions using robotic sensors, coding apps, and building materials, which focuses on engaging students with pragmatic encounters. Concepts like “sequences,” “procedures and algorithms,” and “problem decomposition” highlighted the significance of sequential thinking and problem-solving, skills that aligned with the process of writing code and developing algorithms. The lesson also often connected robotics activities to real-world scenarios and applications. Noteworthy examples included designing a robot for space exploration and student participation in competitive challenges that mimic real-world tasks. This hands-on approach helps students to see the practical applications of what they are learning and a deeper understanding of the mechanical aspects of the robot. Students learn to work with technology tools and gain practical experiences using computational resources.

Educators highlighted the development of cognitive skills such as logical thinking, decision-making, and critical analysis through robot design and coding. Lesson plans frequently incorporated concepts of “conditionals” and “events,” which encouraged students to make decisions based on certain conditions and trigger actions based on specific events reflecting foundational concepts in programming and robotic logic. Chris’s lesson stated:

> The blocks can be explained very logically, like cause and effect in if/then statements or inputs and outputs in sensing blocks. Hint: When trying to program a robot, it is sometimes easier to approach it in steps. If you can write down each step and simplify it as much as possible, you can test the core conditionals of the code without having to fix multiple lines of code every time.

Eric’s lesson articulated, “The benefit of leaving the coding of the bat until after it has been completed is that the students can decide if they want to manually control it or let the robot swing autonomously.”

Critical thinking skills were a focus as students tackled challenges related to gear ratios, designing autonomous behavior, and writing code to control robots. Hands-on, collaborative learning was a common theme in most lesson plans. The objectives emphasized students working in teams, brainstorming, engaging in group discussions, and collaborating to solve challenges. Collaborative learning highlights the importance of teamwork and communication skills in the context of robotics and CT. Chris’s stated learning objectives included, “Introduce the students to VEX IQ sensors and their applications. Students will work in teams to plan for automated functions their robots can perform by adding sensors and electrical wires. Teams will finalize programming using [the] VEX IQ coding app.” He further mentioned, “Main activity–it is expected for this lesson to be slightly more challenging.” Eric articulated, “Work in teams to brainstorm a design for a baseball bat.” He also pointed out, “Main activity–the building phase consists of trial and error.”

The lesson plans were structured with a gradual increase in complexity. Students start with a basic concept, build blocks, and then move to a more advanced challenge. This scaffolding approach ensured students built a strong foundation before tackling more intricate tasks. Technology is also an integral part of the lesson plans. Students use software applications to write and test code, control robots, and stimulate gear ratios. The integration of technology reflects the real-world nature of robotics and prepares students for STEM-related careers.

Educators consistently incorporate reflection as a critical component, encouraging students to analyze their work and identify areas for improvement. Sheila said:

> Encourage campers to use the gears they have pulled from the VEX IQ Super Kit to create different combinations of Driving Gears (on the left) and Driven Gears (on the right) and consider how this would affect speed and torque.

Sandra's lesson plan acknowledged, "Test it: tap the button below to close this tutorial and open the sample program. Then download and run it to test. You can also change the block parameters to optimize how your robot behaves."

Shawn's lesson plan stated:

> Step 4 Reflect: 5 min–have the students answer basic reflection questions about what they completed. It is helpful to review the basics with them, like how the code travels from [the] controller to [the] brain through wires and then to [the] motor. The final questions should be more open-ended, encouraging them to think of other ways they could have achieved the same base or how they could improve the one they are working on.

Self-evaluation promotes critical thinking and the ability to learn from mistakes. The reflection phase enables students to experiment, test, and refine their solutions. The importance of being "incremental and iterative," "testing and debugging," and the use of "trial and error" reflects the iterative process of developing and refining computational solutions.

The integration of robotics and CT with other subjects was evident in some lesson plans. They connected other subjects and linked activities to real-world and practical applications. Examples included geography (studying Mars terrain in NASA-themed challenges), math and physics (understanding speed torque), and mechanical advantages. The interdisciplinary approach enhanced students' understanding of a broader context of robotics and showed CT extended into several other educational curriculum subjects.

The lesson plans also presented students with challenges or scenarios that required them to apply their knowledge creatively; the concepts were introduced to demonstrate their relevance to everyday situations and potential career paths. Chris's planned lesson noted, "Thinking outside the box is an important part of this lesson, and the best way to provide assistance to the teams will be on a case-by-case basis." He also acknowledged, "The main takeaway for students is that they will ultimately be the ones setting the limits of their robot." Eric's lesson plan mentioned, "This will be their first time in the full lesson that they will be building without step-by-step instructions." Vince's lesson plan detailed the following, "Students will run their robots on a prescribed course and calculate the speed of the robots." Vince also noted, "Gears can add speed or torque, but they are inversely proportionate. Gear ratios are either "geared up" or "geared down." Steve's lesson described, "VEX IQ robotics competitions are packed with action." Later, his lesson stated, "These Drivetrain blocks provide the fundamental functions they will be using to control the robot." Shawn's lesson plan proposed the following, "Start the activity by showing the pieces on the board. Define each piece individually, but gradually connect them together, explaining how they come together." He then concluded, "The process of driving is very intuitive, so the students should understand it quickly." This approach encourages students to think outside the box, develop innovative solutions, and bridge classroom learning with practical scenarios. Innovative thinking aligned with the principles of CT that encourage innovative problem-solving and thinking from multiple angles.

The educators' lesson plans consistently introduced and reinforced key vocabulary terms. The introduction to vocabulary terms related to robotics and CT aimed to equip students with a common understanding. CT was also embedded in the iterative process of building, testing, modifying, and understanding robotic systems and their related concepts. These hands-on lessons encouraged students to apply these CT skills in practical scenarios.

Thematic Analysis: Lesson Plans

ER offers an avenue to promote critical thinking in the elementary setting. According to the examined lesson plans, several thematic codes arise in the context of incorporating robotics into pedagogical practices. The analysis discusses the instructor's lesson plans regarding programming concepts, problem-solving and design, abstractions and modularization, data management and analysis, and computational modeling.

Programming Concepts

ER promotes an understanding of programming concepts, which serves as the foundation for developing computational skills in students. Chris's lesson plan emphasized the logical nature of programming by discussing blocks and functions, pointing to cause and effect in if/then statements, and highlighting the importance of inputs and outputs in sensing blocks. Eric's and Shawn's lesson plans further illustrated programming concepts by emphasizing the importance of step-by-step instructions and trial and error, which indicated sequences and iterative processes within programming concepts.

ER provides hands-on experiences that make it easier to grasp programming concepts. In Terri's lesson plan, students were introduced to the VEX Clawbot's control unit, wiring, and joystick—a tangible way to understand sequences in programming where a specific order of operations results in robot movement. Steve and Sheila emphasized the fundamental programming concepts to ensure that students develop a hands-on understanding of how robots operate. In Steve's lesson plan, the importance of understanding basic programming structures, such as sequences, was evident. Steve mentions guiding students through "how to name and save a program," highlighting an understanding of sequences and order of operations ("how to link their robot brain to their iPads"). Moreover, introducing the distinction between commands that initiate movement and commands that dictate movement for a specific period demonstrates experimentation into conditionals.

Problem Solving and Design

Instructors utilized ER to enhance problem-solving skills. The core of Steve's lesson revolved around navigating a maze, a task that requires a comprehensive approach to problem-solving and design. Navigating entails recognizing patterns, particularly in the maze's layout, breaking down the problem of navigation (problem decomposition), and testing different strategies, culminating in an iterative design, prototype, test, and redesign process. Sheila's lesson plan approach involved a series of challenges related to gear ratios, emphasizing pattern recognition, problem decomposition, and assessing different solution paths.

Problem-solving skills were sharpened when students engaged in robotics activities. Terri's lesson plan stressed team collaboration to build and test the Clawbot. This iterative process of design, testing, and redesign process mirrors real-world engineering practices. In Chris's lesson, he mentioned "thinking outside the box" and the importance of trial and error. Here, Chris's lesson promoted understanding pattern recognition, problem decomposition, and the testing-debugging cycle. A key takeaway from Chris's lesson was that while a good build qualifies for competition, the student's ability to problem-solve through programming truly sets them apart.

Abstraction and Modularization

Abstraction and modularization enabled students to compartmentalize problems for efficient resolution. Chris's lesson further emphasized the modular nature of programming by encouraging students to break down their coding challenges into more straightforward steps or blocks. Shawn’s lesson reinforced this theme, with students building the robot in small components that come together, allowing for easier troubleshooting of mistakes.

The incorporation of building on prior knowledge is evident in Steve’s and Sheila’s lessons. Steve introduced students to the VEXcode IQ app, allowing students to build upon their foundational programming knowledge for future projects. Sheila focused on understanding gear mechanisms and their use in different configurations for specific outcomes, such as altering speed and torque. This concept of abstracting a complex problem into simpler parts is a hallmark of CT.

Data Analysis and Management

Data analysis and management were consistent themes, especially in Vince’s lesson. Students were introduced to calculating robot speed and wheel circumference, bridging the gap between physical robotics and abstract data analysis. By having students solve problems based on formulas and practical testing, Vince’s lesson ensured that they engaged in data collection, representation, and manipulation. Sandra’s lesson on EV3 further emphasized data management. The instruction for setting a threshold involved measuring light levels, recording these data points, and then using them to calculate an average. This process highlights data collection, manipulation, and analysis in a tangible manner. Finally, Sheila’s lesson, emphasizing gear ratios, indirectly touched upon data collection and analysis. By experimenting with different gear combinations, students effectively gather data on how each combination impacts speed and torque. Analyzing these outcomes can provide insights into the optimal gear ratios for specific tasks.

Computational Modeling

Computational modeling involves using digital representations to understand real-world scenarios. Vince’s gearing lesson resonated with this theme as students learned to model speed and distance through calculations. Chris’s and Terri’s lessons both indirectly incorporated elements of computational modeling. In Terri’s plan, students can experiment with the VEX curriculum website for configuring and wiring robots, offering potential exposure to computational models used for robot design. Chris’s lesson encouraged students to consider their robots’ physical capabilities and limitations. Students get introductory experience designing and assessing computational models by iterating and refining consistent behaviors. A summary of the thematic analysis of instructors’ lesson plans analysis is shown in Figure 1.

Figure 1

Thematic Analysis: Instructor Lesson Plans

Theme And Frequency	Computational Thinking Codes and Definitions	Instructors							
		Chris	Eric	Sandra	Shawn	Sheila	Steve	Terry	Vince
Programming Concepts 33	Sequences: Basic programming structures and the order of operations.	X	X	X	X	X	X	X	X
	Loops: Techniques for repeating specific actions.					X	X		
	Parallelism: Managing multiple tasks simultaneously.	X	X		X	X	X	X	X
	Events: Triggered actions based on specific occurrences.	X	X	X	X	X	X	X	
	Conditionals: Decision-making in programming.	X		X		X	X		X
	Boolean expression: Logic-based decision criteria				X				
Problem Solving & Design 56	Being incremental and iterative: The iterative process of design, prototype, test, and redesign.	X	X	X	X	X	X	X	X
	Testing and debugging: Identifying and resolving issues.	X	X	X	X	X	X	X	X
	Problem decomposition: Breaking down more significant problems.	X	X	X	X	X	X	X	X
	Preparing problems for computational solutions: Adjusting or reframing issues to be more computationally approachable.	X	X	X	X	X	X	X	X
	Choosing practical computational tools: Deciding on the best tools for the task.	X	X	X	X	X	X	X	X
	Assessing different approaches to a solution: Comparing and selecting from multiple solution paths.	X	X	X	X	X	X	X	X
	Pattern recognition: Identifying repeating or underlying structures.	X	X	X	X	X	X	X	X

Theme And Frequency	Computational Thinking Codes and Definitions (continued)	Chris	Eric	Sandra	Shawn	Sheila	Steve	Terry	Vince
Abstraction and Modularization 24	Reusing and remixing: Incorporating existing solutions or modules.	X	X	X	X	X	X	X	X
	Abstracting and modularizing: Grouping functionality into manageable and reusable chunks.	X	X	X	X	X	X	X	X
	Procedures and algorithms: Step-by-step, exact solution pathways.	X	X	X	X	X	X	X	X
Data Management and Analysis 32	Collecting data: Gathering raw data from various sources.	X	X	X	X	X	X	X	X
	Creating data: Simulating or developing new datasets. Manipulating data: Adjusting, cleaning, or transforming data.	X	X	X	X	X	X	X	X
	Analyzing data: Interpreting data to find insights or patterns.	X	X	X	X	X	X	X	X
	Visualizing data: Creating graphical representations of data for better understanding.	X	X	X	X	X	X	X	X
Computational Modeling 32	Using computational models to understand concepts: Utilizing models as teaching and understanding tools.	X	X	X	X	X	X	X	X
	Using computational models to evaluate solutions: Test solutions without committing to a specific approach.	X	X	X	X	X	X	X	X
	Assessing computational models: Comparing and contrasting models to real-world scenarios.	X	X	X	X	X	X	X	X
	Designing computational models: Conceptualizing and structuring new models.	X	X	X	X	X	X	X	X

Note. The chart shows whether a theme is present in the data, not the frequency of its occurrence in each participant's data.

The findings from this study aligned with previous research. The identified themes aligned closely with prior knowledge and did not present significantly divergent perspectives. The recurring themes remain consistently dominant, serving as an indication of reaching saturation (Creswell, 2013).

Research Questions

Incorporating robotics in education fosters critical thinking and enriches the teaching experience. Chris's lesson stated his theory that programming is integral to success in robotics competitions, emphasizing its practical implications. Eric's lesson underscored the significance of hands-on experience, advocating for the exploratory design of robots without predetermined instructions. Vince's lesson focused on the relationship between theory and practice, with mathematical concepts translated into tangible robotic outcomes.

Lastly, Shawn's lesson emphasized foundational knowledge, ensuring students understand the basics of each robot part before assembly. The lesson plans showcased that ER is a powerful tool to nurture critical thinking among elementary students. Through hands-on experiences, students grasp complex programming concepts, develop problem-solving skills, and explore data analysis.

Research Question 1

RQ1. How do instructors describe the use of educational robotics to promote critical thinking skills among elementary students?

Through their distinct approaches, the instructors highlighted the multifaceted benefits of integrating robotics into education, fostering computational and critical thinking. These lesson plans' trends and emerging themes reveal that instructors aim to foster critical thinking by promoting problem-solving, active learning, design iteration, and experiential engagement.

The lesson plans highlighted various ways instructors integrated CT principles in ER. This thematic analysis underscores the dynamic intersection of robotics education and CT, with educators as pivotal conduits. Overall, these lesson plans reflect the commitment of educators to preparing elementary students with skills necessary for a technologically advanced world.

Research Question 2

RQ2. What are instructors' perspectives on the development of computational thinking using educational robotics?

The perspectives of instructors on developing CT using ER were positive and proactive. The lessons incorporated elements of CT, from understanding basic programming concepts to the hands-on application of these concepts in problem-solving scenarios. Instructors recognized the value of using robotics as a tangible tool for instilling CT. Their perspectives on developing CT with robotics were grounded in tangible experiences, emphasizing the importance of iterative learning, data analysis, and understanding the abstract layers of programming.

Analysis of Data Source 2: Instructors' Surveys of Student Work

Instructors supplied examples of student work samples, and the secondary data source came from a written survey (see Appendix C) where instructors discussed these student work samples.

Thematic Analysis: Instructors' Surveys Questions of Student Work

Based on the teacher surveys (see Appendix C), the analysis provided data on several key themes that emerged in relation to focusing on the use of ER to promote critical thinking among elementary students and the instructors' perspectives on developing CT using these robotic tools. There were a few notable trends from the instructors' survey that were not directly from computational code. It is necessary to mention them because they provide additional context for understanding instructors’ perspectives.

The educators unanimously described the classroom environments as interactive, conducive to collaboration, and explorative. Sandra, Eric, and Shawn observed collaborative working tendencies among students. Participant Sandra shared, “The students worked collaboratively [with] each other.” In addition, Eric explained, “The students worked in teams for this lesson,” to emphasize the importance of teamwork in solving complex challenges.

All educators played facilitative roles, guiding students as needed and emphasizing hands-on learning. Autonomy allowed students to apply cognitive skills like logical reasoning and critical thinking, as noted by Sandra and Eric. Eric shared, “The most noticeable cognitive skills applied were creativity, sustained attention, and logical thinking.” Sandra explained, “One of the cognitive skills applied is logical reasoning.” While some activities were more guided, such as Shawn’s VEX IQ robot building, others, like Eric’s bat attachment task, required greater cognitive application, fostering creativity, sustained attention, and logical reasoning.

Programming Concepts

ER employs multiple programming concepts, offering students an understanding of sequences, loops, parallelism, events, conditionals, and Boolean expressions. As observed in Steve’s response, using the VEXcode IQ app for programming VEX IQ robots exposed students to block coding, reminiscent of the popular Scratch interface, allowing students to navigate through mazes.

Steve said:

> This assignment is a really good introduction activity for programming VEX IQ robots on the VEXcode IQ app. The app is packed with so many helpful features, my favorite

> being the format. It resembles that of the scratch coding website and app, which a lot of students have used before enrolling in the course. For the block coding option, it feels like a design standard that should be used across all robotics platforms.

Incorporating these concepts, from primary sequences to Boolean logic, exemplifies how robotics can serve as a conduit for introducing elementary students to intricate programming ideas.

The EV3 robot project described by Sandra and the VEX IQ robot task detailed by Shawn underscored the foundational programming concepts essential for the tasks. Sandra highlighted the following:

> The student assignment was to create an EV3 robot base with the line sensor attachment. Once the students completed the build of the robot, they were then tasked with programming the robot to follow a black line. This was supported with [sic] a lesson on algorithms and how programming works. In order to successfully complete the task, students learned the concepts of a loop and a switch statement in programming.

In contrast, Shawn did not dwell heavily on programming; however, he alluded to preloaded programming on the robot's brain. He stated, "Once the robot was built, the students were then able to control the robot via remote control with the program already on the brain of the robot."

Problem Solving and Design

The theme of problem-solving and design was central to integrating ER into the curriculum. For instance, Sheila's gear ratio simulator lesson with the VEX IQ parts illustrated the iterative design, prototype, test, and redesign process. Sheila explained, "The student assignment was to create a gearbox in order to better understand the concept of torque and speed as well as the tradeoff between the two," and "students were then given challenges to apply what to learn to create different gear ratios." Vince's sumo-bot wrestling activity, where students must contemplate the strength of structures, gear ratios, and more, exemplified problem decomposition and pattern recognition. Vince said:

> The assignment is all about computational thinking. This starts with the calculation of the strength of the structure. Teams planned structures that they thought would be strong and resistant to the pressure of the wrestling competition. This included applying gear ratios that make the robot's wheels move faster while applying gear ratios on the arms that make the robot stronger.

Such activities encourage students to break down challenges, compare solutions, and identify patterns, fortifying their problem-solving skills. The iterative design, testing, and redesign process was evident across all the surveys.

Sandra's students faced challenges in programming the robot to follow a line. Participant Sandra revealed, "For the programming, the students had a more difficult time understanding how to get the robot to follow the line. Physical demonstrations were very helpful for the programming aspect." Chris noted, "Students experimented with variables to achieve different outcomes," and Eric indicated, "Students demonstrated a straightforward iterative approach, modifying their bat designs based on trial and error." These themes captured the essence of problem decomposition, pattern recognition, and testing and debugging.

Abstraction and Modularization

Many teachers' responses highlighted the process of reusing, remixing, and abstracting information into manageable chunks. Terry's claw-bot building assignment using visual instructions on iPads showed how students employ procedures and algorithms. Terry asserted, “The students demonstrated several computational thinking principles during the assignment. They included procedures and algorithms as they use step-by-step instructions to build their base.” This idea of leveraging prior knowledge or existing modules—whether they are code snippets or construction techniques—allowed students to handle more complex projects by compartmentalizing them into more straightforward, more approachable tasks.

Eric’s survey highlighted this theme most prominently. Students in his class displayed abstraction by visualizing a robotic baseball bat attachment, while modularization was evident as they integrated the bat into their existing robot designs. This reuse and remix approach, demonstrated by borrowing ideas from an instructor’s design, emphasized the utility of existing solutions. Eric explained, “Reusing and remixing was another large part of this lesson as many of the teams tried to base their design off of an instructor-designed bat robot.”

Data Management and Analysis

Data management and analysis encompassed several key processes. First, there was the act of collecting data, which involved sourcing raw information from diverse origins. Eric’s survey revealed that “The students were mostly trying to solve the problem by using testing and debugging, in each team, the bat design went through a process of trial and error before the team would come to a final decision.” Vince noted, “The assignment is all about computational thinking. This starts with the calculation of the strength of the structure.” The creation of data follows, where new datasets are either simulated or developed. Once data is acquired, it often requires manipulation, which can include adjusting, cleaning, or even transforming the information to ensure it is usable. Eric noted data manipulation in his student’s work, “When one team built a bat, they found that the size was too large for the robot to stay upright while in motion, so they reduced the size and tried again.” Vince noted, “This included applying gear ratios that make the robot’s wheels move faster while applying gear ratios on the arms that make the robot stronger.” After refining the data, it is essential to analyze it, seeking out insights or discerning underlying patterns. The final step in this process is visualizing the data. This entails crafting graphical depictions of the information, enhancing comprehension, and offering a clearer perspective on the data’s significance. Steve noted:

> This assignment is a really good introduction activity for programming VEX IQ robots on the VEXcode IQ app. It resembles that of the scratch coding website and app, which a lot of students have used before enrolling in the course.

Computational Modeling

Vince’s assignment provided a glimpse into computational modeling. When building the sumo-bot wrestling robot, students must contemplate and make decisions based on their understanding of the mechanics—like gear ratios and structure strength. Vince acknowledged:

> Teams planned structures that they thought [would] be strong and resistant to the pressure of the wrestling competition. This included applying gear ratios that make the robot’s wheels move faster while applying gear ratios on the arms that make the robot stronger.

This signified deploying computational models to understand concepts and evaluate potential solutions. The modeling theme was illustrated best in Eric’s lesson. Students designed a bat-like attachment and incorporated programming to simulate its behavior. Eric explained:

> The students had to come up with ideas for how to design a baseball bat-like attachment to their VEX IQ robot. Once the construction of the bat is complete, the students add the programming for how the bat would work and test out the design. Once the main objectives were complete, they could try to look for any other changes they could make with the new addition, including any issues it may have caused to the main chassis.

Integrating physical design with software modeling captures the essence of computational modeling as a teaching tool. Figure 2 illustrates the thematic analysis of the instructor surveys of student work and the recurrence of each theme among the participants.

Figure 2

Thematic Analysis: Instructor Survey of Student Work

Theme And Frequency	**Computational Thinking Codes and Definitions**	**Instructors**							
		Chris	Eric	Sandra	Shawn	Sheila	Steve	Terry	Vince
Programming Concepts 34	Sequences: Basic programming structures and the order of operations.	X	X	X	X	X	X	X	X
	Loops: Techniques for repeating specific actions.		X	X		X			X
	Parallelism: Managing multiple tasks simultaneously.	X	X		X		X	X	
	Events: Triggered actions based on specific occurrences.	X				X	X	X	X
	Conditionals: Decision-making in programming.		X	X		X	X	X	X
	Boolean expression: Logic-based decision criteria			X	X	X	X	X	X
Problem Solving & Design 40	Being incremental and iterative: The iterative process of design, prototype, test, and redesign.	X	X	X	X	X	X	X	X
	Testing and debugging: Identifying and resolving issues.	X	X	X	X	X	X	X	X
	Problem decomposition: Breaking down more significant problems.	X	X			X	X	X	X
	Preparing problems for computational solutions: Adjusting or reframing issues to be more computationally approachable.	X				X	X		
	Choosing practical computational tools: Deciding on the best tools for the task.	X	X		X		X	X	
	Assessing different approaches to a solution: Comparing and selecting from multiple solution paths.			X		X	X		X

	Pattern recognition: Identifying repeating or underlying structures.		X	X	X		X		X
Theme And Frequency	**Computational Thinking Codes and Definitions (continued)**	Chris	Eric	Sandra	Shawn	Sheila	Steve	Terry	Vince
Abstraction and Modularization 21	Reusing and remixing: Incorporating existing solutions or modules.	X	X	X	X	X	X		X
	Abstracting and modularizing: Grouping functionality into manageable and reusable chunks.	X		X	X	X		X	X
	Procedures and algorithms: Step-by-step, exact solution pathways.	X	X	X	X	X	X	X	X
Data Management and Analysis 32	Collecting data: Gathering raw data from various sources.	X	X	X	X	X	X	X	X
	Creating data: Simulating or developing new datasets. Manipulating data: Adjusting, cleaning, or transforming data.	X	X	X	X	X	X	X	X
	Analyzing data: Interpreting data to find insights or patterns.	X	X	X	X	X	X	X	X
	Visualizing data: Creating graphical representations of data for better understanding.	X	X	X	X	X	X	X	X
Computational Modeling 32	Using computational models to understand concepts: Utilizing models as teaching and understanding tools.	X	X	X	X	X	X	X	X
	Using computational models to evaluate solutions: Test solutions without committing to a specific approach.	X	X	X	X	X	X	X	X
	Assessing computational models: Comparing and contrasting models to real-world scenarios.	X	X	X	X	X	X	X	X
	Designing computational models: Conceptualizing and structuring new models.	X	X	X	X	X	X	X	X

Note. The chart shows whether a theme is present in the data, not the frequency of its occurrence in each participant's data.

Research Questions

Research Question 1

RQ1. How do instructors describe the use of educational robotics to promote critical thinking skills among elementary students?

The survey (see Appendix C) responses highlighted the multifaceted use of ER in fostering critical thinking. In the realm of robot building and design, tasks often revolve around students designing robots or adding unique features. As Vince mentioned, “Students were grouped into teams and asked to build and program a sumo-bot ‘wrestling’ robot.” Eric further elaborated on the creativity and logical thinking involved by stating, “The students had to come up with ideas for how to design a baseball bat-like attachment to their VEX IQ robot.”

When it came to programming and coding, students were introduced to a spectrum of activities, from elementary block coding to intricate algorithms. Steve highlighted this by noting, “The students are only expected to use the Drivetrain blocks.” As students dabble in these tasks, they deploy trial and error methods, enhancing their problem-solving skills. Sandra emphasized the integration of CT principles and said, “The student assignment was to create an EV3 robot base with the line sensor attachment with a lesson on algorithms and how programming works.”

Collaboration and teamwork were pivotal in these activities. As Eric detailed, “The students worked in teams for this lesson. The teams typically comprised groups of 2–3 kids.” This teamwork occasionally results in variances in group dynamics, but as Steve documented, “Robotics is usually done in teams,” ensuring collaborative learning.

The instructor’s role was often that of a facilitator. Eric elucidated this and stated, “The instructors acted more so as facilitators,” while Vince commented on the instructor’s emphasis on student creativity and said, “For this assignment, the students were expected to express the creativity and the unique ideas of the team. The teacher only served as a facilitator.”

Describing the classroom environment, Eric mentioned the systematic setup. He said, “The classroom environment was set up like a typical classroom where the tables are lined up and organized for small groups.” Sandra added that such environments were spacious enough for active building activities and said, “The classroom environment was a big classroom that consisted of a space for building robots; each team [was] assigned to a separate table.”

There were evident variations in enthusiasm and approach regarding student engagement and cognitive skills. Eric observed the application of “creativity, sustained attention, and logical thinking.” Steve, on the other hand, pointed out the diversity of cognitive skills applied, “In an average class, you will see each team apply at least one different cognitive skill than the other.”

Lastly, in discussing gender dynamics, differences in male and female student engagement patterns were noted. Vince’s observation was quite telling. He commented, “Male students tend to be more likely to dive in without worrying about failure. The female students tend to be more reflective.” Steve also shared insights, noting that during building tasks, “male students tend to tackle the challenge with the goal of making a better robot than the other teams, whereas the females tend to aim for a well-done result.”

Research Question 2

RQ2. What are instructors’ perspectives on the development of computational thinking using educational robotics?

From the instructors’ perspective, ER was an effective means to cultivate CT. ER presented a multifaceted approach to fostering critical and CT among elementary students. Instructors unanimously agreed on the potential of ER in promoting critical and CT among elementary students. Eric emphasized the guiding role of examples, noting, “Initially, the students didn’t seem to understand what to do ... until they were able to see an example.” He further highlighted the significant roles of “creativity, sustained attention, and logical thinking.” Vince, focusing on foundational knowledge, said students were “expected to be creative and build based on their learned knowledge.” He also discerned gender-specific approaches, pointing out how “male students tend to dive in. The female students tend to be more reflective.”

Steve promoted user-friendly tools and stated, “The app resembles the scratch coding website and app.” Terry outlined a structured collaboration and commented, “The students work in collaborative groups of three,” and noted gendered engagement differences in his observation. Chris acknowledged the benefits of autonomous programming, saying students understood that “instructing a robot to drive without a controller is possible.” Sandra believed that “physical demonstrations were very helpful for the programming aspect,” while Shawn emphasized the direct, hands-on approach, admitting that students “really didn’t have the opportunity to demonstrate computational thinking principles.” Finally, Sheila stressed the significance of understanding key robotics concepts, pointing out that the assignment was “to create a gearbox to understand the concept of torque and speed.” Collectively, these perspectives underscored the intertwined relationship between ER and CT, all while emphasizing the unique insights and challenges perceived by different instructors.

Analysis of Data Source 3: Instructors’ Interviews

Instructor interviews (see Appendix D) provided data with several emerging themes related to the instructors’ perspectives on the goals of ER instruction and its application in promoting critical thinking and CT in elementary students.

In addition to CT, instructors highlighted robotics as a useful tool to prepare students for the future, building interpersonal skills and teamwork and exposure to fields of robotics and engineering.

The instructors appeared unanimous in their belief that instruction in robotics prepares students for the future. Vince emphasized, “To prepare students for the future workforce by teaching them how to utilize critical thinking, algorithmic thinking, and communications skills.” Eric and Steve both alluded to how robotics education readies students for technology’s increasing role in daily lives and offers a glimpse into perspective career fields. Eric mentioned:

> The goal of robotics education is to increase the level of process thinking (computational thinking) in students. The instruction also exposes students to technology that is becoming a more common part of everyday life and it allows them to view related career fields as valid options for the future.

Steve indicated:

> The goal of robotics instruction is to prepare students for a variety of engineering-oriented careers while also integrating with the core subjects to help them develop cognitive skills and computational thinking ... Offering courses that promote industry-ready ideals can be the start of a career path for all students, engineering or not.

Steve’s interview discussed how robotics develops interpersonal skills. Steve asserted, “Another overlooked skill that educational robotics can offer is teamwork; that includes team building, scouting members, leadership, and professionalism.” Such skills are indispensable in the real world and further justify the importance of robotics in schools. Several instructors highlighted the importance of merely exposing students to the field of robotics and the broader domain of engineering. Shawn said, “The goal of the robotics instruction was to introduce the students to robotics acts as a pipeline to eventually study engineering." Eric said, "The instruction also exposes students to technology that is becoming a more common part of everyday life, and it allows them to view related career fields as valid options for the future."

Steve mentioned, "The goal of robotics instruction is to prepare students for a variety of engineering-oriented careers. Offering courses that promote industry-ready ideals can be the start of a career path for all students, engineering or not." Shawn focused on raising awareness of robotics and stated, "The goal of the robotics instruction was to introduce the students to robotics ... they will become aware that they have the power to engage in creativity and construction, which acts as a pipeline to eventually study engineering." Exposure to robotics and its diverse applications could serve as a catalyst for nurturing critical thinking among students.

Thematic Analysis: Instructors' Interviews

This thematic analysis examined the data from the teacher interviews (see Appendix D). The data collected from the interviews provided insight into teachers' experiences and perspectives on developing CT using ER in the elementary school setting. This thematic analysis provided data on several key themes to focus on using ER to promote critical thinking among elementary students.

Programming Concepts

ER is pivotal in introducing elementary students to programming concepts. When discussing the goal of robotics instruction, teachers like Sandra and Shawn noted its utility in enabling students to understand the process of building and programming robots for specific tasks. Shawn believed, "The goal of the robotics instruction was to introduce the students to robotics. Robotics is a very cool field, and often students aren't aware of it outside of TV." Sandra stated, "The goal of robotics instruction is to allow students to experience robotics through the process of building one’s own robot and learning how to program that robot to accomplish the task.” Sheila articulated, “Based on my experience, students often do not have well-developed critical thinking skills, and thus educational robotics is a great means to develop computational thinking.” Chris also supported this sentiment and said:

> The goal of educational robotics was to give the younger kids a head start in STEM education and help them understand a rapidly modernizing world. Within 2 to 3 days of the program, almost all the students in each class I’ve seen have shown a very strong interest in at least some aspects of STEM [emphasizing the benefits of giving students a head start in STEM education].

In their interviews, the instructors emphasized the importance of foundational vocabulary in understanding CT. As Sheila and Steve both highlighted, students used terms like “testing” and “debugging.” Terry further emphasized that students often reference “step-by-step instructions,” while Vince highlighted words such as “build,” “program,” and “measure.”

Problem-Solving and Design

Robotic instruction promotes problem-solving and design skills. When asked if ER helped students develop CT skills, all instructors believed it enabled students to “think critically and solve problems.” As Eric articulated, the challenges associated with “designing, building, and programming a robot without step-by-step instructions” naturally demand CT. Shawn echoed similar sentiments and said, “Robotics education forces students to think about problems in a unique way that [is] not typical of the regular educational curriculum.” Sandra articulated:

> Yes, because it allows students to think critically and solve problems that arise throughout the engineering process. When building and programming a robot, if things

> don’t work the first time and so the students quickly learn to iterate and try something new to get something to work.

Eric responded, “I think educational robotics helps students develop computational thinking skills because the process of designing, building, and programming a robot without step-by-step instructions requires the use of computational thinking even without being primed to do so.”

A consistent theme across the interviews was the value of problem-solving. Sheila mentioned, “Robotics is an engineering design process is a circular process that requires designing, testing, and making modifications.” Steve emphasized students’ core CT strategies, such as “sequences, loops, events, conditionals, testing and debugging, procedures and algorithms, problem decomposition, collecting data, and pattern recognition.” Vince also highlighted the critical importance of “measurement, planning, time management, communications, documentation, analysis, adjustment, practice, pattern recognition, and debugging.”

Abstraction and Modularization

Several instructors touched on abstraction, which simplified complex problems or tasks into smaller, more manageable components. Sandra’s students, for instance, were “implementing abstraction” when trying to solve problems. Shawn also mentioned the importance of students using abstraction and recognizing patterns and said:

> There was some abstraction and pattern recognition being used by the students. Robotics allows students to take individual pieces, put them together, and build something that is an unrecognizable machine that can actually complete a commanded task. As the

> instructor and coach, I am consistently encouraging students to look for symmetry to create a stable build. So, it is important to recognize patterns for successful builds.

While not explicitly termed as such, the essence of abstraction and modularization was evident. For instance, Terry's mention of students using "sequencing, events, and conditional" highlighted the idea of breaking down complex tasks into smaller, more manageable ones. Eric emphasized:

> The computational thinking strategies are definitely sequences, events, and testing and debugging, the process of building robots is following steps so that one action causes another action, and if the action is not the intended action, you test and make adjustments based on the desired outcome.

Data Management and Analysis

Data management and analysis skills also emerged from robotics instruction. The iterative process—where students repeatedly refine their robotic instructions based on test results—spoke to the core of CT. Eric stated:

> The process of designing, building, and programming a robot without step-by-step instructions requires the use of computational thinking even without being primed to do so. For example, when students were told to program their robot to go through a maze, they had to use testing and debugging and collecting data to solve the maze.

The feedback loop essential for data analysis was evident in Sheila's explanation: "Robotics, for example, is a great tool that allows students to self-correct. Because robotics provides immediate feedback, students can re-examine their build and self-correct by trying another approach for the solution or the desired result." Vince discussed how students work within constraints and use sensors and said, "Students definitely develop computational skills.

They work within the constraints by building to the optimized dimensions, arranging the gear ratios for speed and/or [sic] torque, by managing the materials, and by deploying sensors that respond to the physical environment."

Computational Modeling

The use of ER naturally promotes computational modeling, allowing students to build and refine models of how their robots should function in each environment. Eric's students, for instance, needed to consider sequences, events, and test outcomes to ensure their robots could tackle given challenges. Instructors emphasized the importance of hands-on learning. Steve highlighted the significance of robotics courses in bridging the gap between theory and application, especially in developing cognitive skills and CT. He said, "The goal of robotics instruction is to prepare students for a variety of engineering-oriented careers while also integrating with the core subjects to help them develop cognitive skills and computational thinking." Figure 3 illustrates the thematic analysis of the instructor interviews and the recurrence of each theme among the participants.

Figure 3

Thematic Analysis: Instructor Interview Results

Theme And Frequency	**Computational Thinking Codes and Definitions**	**Instructors**							
		Chris	Eric	Sandra	Shawn	Sheila	Steve	Terry	Vince
Programming Concepts 24	Sequences: Basic programming structures and the order of operations.	X	X	X	X	X	X	X	X
	Loops: Techniques for repeating specific actions.	X					X		
	Parallelism: Managing multiple tasks simultaneously.						X		
	Events: Triggered actions based on specific occurrences.		X				X	X	X
	Conditionals: Decision-making in programming.	X	X	X	X	X	X	X	X
	Boolean expression: Logic-based decision criteria			X					
Problem Solving & Design 37	Being incremental and iterative: The iterative process of design, prototype, test, and redesign.	X	X	X	X	X	X	X	X
	Testing and debugging: Identifying and resolving issues.	X	X	X	X	X	X	X	X
	Problem decomposition: Breaking down more significant problems.	X	X		X		X	X	X
	Preparing problems for computational solutions: Adjusting or reframing issues to be more computationally approachable.		X						X
	Choosing practical computational tools: Deciding on the best tools for the task.					X		X	
	Assessing different approaches to a solution: Comparing and selecting from multiple solution paths.	X		X	X	X	X		X
	Pattern recognition: Identifying repeating or underlying structures.	X			X	X	X		X

Theme And Frequency	**Computational Thinking Codes and Definitions (continued)**	Chris	Eric	Sandra	Shawn	Sheila	Steve	Terry	Vince
Abstraction and Modularization 21	Reusing and remixing: Incorporating existing solutions or modules.			X		X	X	X	X
	Abstracting and modularizing: Grouping functionality into manageable and reusable chunks.	X	X	X	X	X	X	X	X
	Procedures and algorithms: Step-by-step, exact solution pathways.	X	X	X	X	X	X	X	X
Data Management and Analysis 21	Collecting data: Gathering raw data from various sources.		X	X	X	X	X	X	X
	Creating data: Simulating or developing new datasets. Manipulating data: Adjusting, cleaning, or transforming data.	X	X	X		X	X	X	X
	Analyzing data: Interpreting data to find insights or patterns.		X	X	X	X	X	X	X
	Visualizing data: Creating graphical representations of data for better understanding.								
Computational Modeling 31	Using computational models to understand concepts: Utilizing models as teaching and understanding tools.	X	X	X	X	X	X	X	X
	Using computational models to evaluate solutions: Test solutions without committing to a specific approach.	X	X	X	X	X	X	X	X
	Assessing computational models: Comparing and contrasting models to real-world scenarios.		X	X	X	X	X	X	X
	Designing computational models: Conceptualizing and structuring new models.	X	X	X	X	X	X	X	X

Note. The chart shows whether a theme is present in the data, not the frequency of its occurrence in each participant's data.

Research Questions

Research Question 1

RQ1. How do instructors describe the use of educational robotics to promote critical thinking skills among elementary students?

Shawn asserted, "I believe that educational robotics does help students develop computational thinking skills because robotics education forces students to think about problems in unique ways that are not typical of the regular educational curriculum." Eric noted:

> I think educational robotics helps students develop computational thinking skills because the process of designing, building, and programming a robot without step-by-step instructions requires the use of computational thinking even without being primed to do so. For example, when students were told to program their robot to go through a maze, they had to use testing and debugging and collecting data to solve the maze.

Sheila stated, "Educational robotics allows me to make STEM concepts more fun and engaging." Additionally, she mentioned, "Robotics, for example, is a great tool that allows students to self-correct. Because robotics provides immediate feedback, students can re-examine their build and self-correct by trying another approach for the solution or the desired result." Steve believed the following:

> Robotics courses differentiate themselves from core subjects because they offer hands-on challenges that involve logical reasoning and physical skills. Challenges can get more intricate as the course continues, but the approach that students take will be more efficient every time.

Terry acknowledged the following:

> I do believe that robotics helps students develop computational skills. The nature of building robots is using a step-by-step process to build and trial and error to find solutions. As students participate in educational robotics, they practice computation thinking.

Vince explained:

> Yes, students definitely develop computational skills. They work within the constraints by building to the optimized dimensions, arranging the gear ratios for speed and/or [sic] torque, by managing the materials, and by deploying sensors that respond to the physical environment.

Research Question 2

RQ2. What are instructors' perspectives on the development of computational thinking using educational robotics?

The semistructured interviews revealed several recurrent themes regarding using ER to promote critical thinking and CT among elementary students. Steve noted:

> Robotics courses differentiate themselves from core subjects because they offer hands-on challenges that involve logical reasoning and physical skills. Challenges can get more intricate as the course continues, but the approach that students take will be more efficient every time. In other subjects, this effect is clearly shown in comparison to the learning curves of students [who] are not enrolled in robotics.

Both Terry and Vince strongly believed in the role of ER in fostering CT. Terry stated:

> I do believe that robotics helps students develop computational skills. The nature of building robots is using a step-by-step process to build and trial and error to find

> solutions. As students participate in educational robotics, they practice computation thinking.

Additionally, Vince emphasized:

> Yes, students definitely develop computational skills. They work within the constraints by building to the optimized dimensions, arranging the gear ratios for speed and/or [sic] torque, by managing the materials, and by deploying sensors that respond to the physical environment.

Sheila emphasized the relevance of ER in developing CT, observing that students who engage long-term with robotics tend to pursue STEM majors. She stated:

> Yes, based on my experience, students often do not have well-developed critical thinking skills, and thus, educational robotics is a great means to develop computational thinking. I’ve found that of the students [who] have had experience in robotics long-term, they are more likely to go into a STEM major and stick with it.

Instructors see ER as a useful tool for fostering critical and CT among elementary students. Through hands-on experiences and immediate feedback, students engage deeply with core computational concepts, preparing them for future STEM-oriented careers. Educators emphasize the importance of integrating robotics into the curriculum to foster CT in students. The perspectives of these educators provide insights into how robotics can promote skills beyond just programming.

Sandra explained, “The goal of robotics instruction is to allow students to experience robotics through the process of building one’s own robot and learning how to program that robot to accomplish the task.” She believed that “educational robotics is also very good at generating curiosity or motivation to explore a career in education.” Moreover, she noted that students utilize computational thinking terms, such as “AND” and “OR,” without even realizing it.” Chris pointed out that “The goal of educational robotics was to give the younger kids a head-start in stem education and help them understand a rapidly modernizing world.” He firmly believed that “robotics definitely encourage high-level computational thinking skills in kids.” Eric suggested, “The goal of robotics education is to increase the level of process thinking (computational thinking) in students.” He added, “Educational robotics helps students learn how to work in teams, solve complex problems, and think outside the box.” Shawn said, “Educational robotics does help students develop computational thinking skills because robotics education forces students to think about problems in unique ways.” Sheila highlighted the following and said, “The goal of my robotics instruction is to introduce students to STEM concepts in a hands-on way.” She commented, “Educational robotics is a great means to develop computational thinking.” Steve mentioned, “The goal of robotics instruction is to prepare students for a variety of engineering-oriented careers while also integrating with the core subjects to help them develop cognitive skills and computational thinking.”

Conclusion

The data sheds light on the primary research questions. First, as described by instructors, ER served as a hands-on tool to cultivate critical thinking, especially when students are encouraged to overcome initial challenges and explore solutions. Second, the instructors viewed these activities as essential for developing CT, especially when students can access intuitive tools, prior experience, and practical examples to guide their learning journey.

The analysis findings validate prior research on the importance of hands-on and experimental learning and offer a deeper insight into the role of collaborative problem-solving in CT. Past research may have identified the individual components of CT or the benefits of hands-on activity. The next chapter will discuss how this analysis bridges the two, highlighting how they enhance each other within the context of ER in elementary school students.

Chapter 5: Discussion, Conclusions, and Recommendations

ER is a flourishing tool in K–12 classrooms aimed at fostering the development of CT among students. ER seeks to bridge the gap between traditional screen-based and physical computing, providing students with tangible, real-world applications of computational concepts. While the use of robotics in education has been applauded for its potential to increase student engagement, motivation, and interest in STEM fields, there exists a need to delve deeper into understanding its impact, particularly on elementary students.

CT, defined in the 1980s, is not just about thinking like a computer but is a broad and multifaceted approach to problem-solving that encompasses decomposition, pattern recognition, abstraction, and algorithmic thinking. The applicability of CT extends far beyond computer science and has been publicized as an essential skill for the 21st century. Mastery is believed to increase potential relevance to employability in STEM careers.

However, despite its importance, there seems to be a deficiency in CT skills among K–12 students, as evidenced by academic performance metrics in Texas.

This qualitative descriptive study focused on Texas, a state with a significant student population but very limited data on the number of dedicated robotics instructors. By targeting instructors involved in robotics education, the study garnered insights into the role of ER in honing elementary students' CT abilities. Specifically, the study answered how instructors perceive the utility of robotics in fostering critical thinking and their perspectives on the development of CT facilitated by robotics.

Discussion

Using Papert's (1980) constructionism theory as an anchoring framework, the results provided robust evidence for the intricate interplay between robotics education and the amplification of CT. Consistent with Papert’s (1980) assertions, students actively construct knowledge through a blend of experiences and ideas, reflecting the central premise of constructionism that knowledge arises from the interplay between one’s experiences and conceptualizations. In this environment, educators transitioned from mere knowledge dispensers to facilitators, steering learners as they construct concepts grounded in their personal experiences and contemplations. The tangible objects, notably the robot, served as a tool that facilitates and fosters knowledge construction, aligning with Papert’s (1980) and Papanastasiou et al.’s (2019) position on the potential of hands-on learning.

The study brought to the forefront the value of experiential learning, mirroring the findings by Mayoral-Rodríguez et al. (2018) and Kong (2021), both of whom advocated for hands-on activities as catalysts for enhancing problem-solving and engagement levels. However, as Moye et al. (2017) pointed out, many instructional frameworks lack such hands-on opportunities. Integrating more experiential learning instances, such as through ER, could address this educational void, creating a deeper bond between students and the knowledge they gain.

Furthermore, the data generated from the educators’ lesson plans, surveys, and interviews consistently emphasized the significance of experiential learning and collaborative problem-solving in fostering both computational and critical thinking. In the realm of CT, it was evident that it was not merely an isolated cognitive endeavor. Instead, it was linked with components of social interactions, communications, and teamwork. As students engaged in group activities such as coding or debugging, they were compelled to explain their thought processes, solicit feedback, and collaboratively refine solutions. This multifaceted approach to CT is underscored by the findings, which suggest it naturally ties to a broad spectrum of learning processes. Consequently, it becomes evident that CT seamlessly combines varied subjects and pedagogical activities.

Additionally, the results signified a compelling correlation between ER and the growth of object recognition skills, echoing Bers et al.'s (2002) claim that such capabilities act as a bridge between abstract theories and tangible real-world applications. Instructors have noted that students, when exposed to “powerful ideas,” as articulated by Papert (1980) and Holbert (2016), could compare the academic content within broader real-world frameworks, enriching knowledge retention and fostering a comprehensive understanding (Kelter et al., 2021; Makri et al., 2015).

The study's findings underscored that a thriving robotics curriculum exceeds technical understanding. It combined elements within a broader canvas of collaboration, communication, and problem-solving. As the educators' role evolved in steering the trajectory of CT, it is evident there is a need for continuous professional enrichment, ensuring educators remain adept in cultivating collaborative problem-solving mindsets.

Limitations

This study was not without its limitations. The data collected from the surveys and interviews relied on self-reported data, which could be influenced by recall bias and subjective interpretation. Another consideration was the vast landscape of Texas education, combined with the limited percentage of dedicated robotics instructors and the variation in how robotics is offered (either as an enrichment class or an after-school program), which might introduce variability in the findings. Also, the research primarily focused on educators' perspectives; the study did not examine the student's viewpoints and experiences, which are essential to understanding the full impact of ER on learning. Lastly, analyzing qualitative data from interviews can be subjective. Even though patterns and trends can be identified, different researchers might interpret the data differently. My interpretations could introduce an element of subjectivity to the conclusions.

Results and Analysis

The study on instructors' perspectives of using Lego® EV3 and VEX IQ ER platforms in elementary settings, based on lesson plans, surveys of student work, and teacher interviews, generated vital insights. Instructors overwhelmingly viewed robotics as an invaluable tool to stimulate critical and CT. Through thematic analysis, it emerged that instructors, while using distinct methods, collectively viewed robotics as a platform that encouraged problem-solving, hands-on engagement, and iterative learning. These approaches directly mapped to fostering critical and CT, with robotics as a dynamic medium to bridge abstract computational concepts with tangible learning experiences. Additionally, this integration was viewed as a mere STEM introduction and a comprehensive method to cultivate various CT facets.

Significance and Contribution to Prior Research

These results resonated with Papert's (1980) constructionism theory, asserting that knowledge is best acquired through hands-on experiences and tangible project building. The outcomes also corroborated the findings of Blikstein (2018), Bers et al. (2002), and others who emphasized the "learning by doing" paradigm. The study further shed light on the value of robotics as a tool for experiential learning, aligning with Kolb's (1984) framework, which propounds the benefits of directly engaging with materials for enhanced knowledge retention. Consequently, the study contributed significantly to the existing literature by reinforcing the importance of experiential learning through robotics in fostering CT, especially in elementary settings. This understanding is instrumental for educational leaders in Texas and beyond to integrate robotics meaningfully in their curricula to develop computational and critical thinking skills among students.

Implications

ER has been increasingly recognized as a potent medium for elementary students to foster critical thinking and computational skills. Amid the rapidly evolving technological landscape, there is a growing emphasis on equipping learners with 21st-century skills. Examinations of lesson plans, surveys of student work, and semistructured interviews were conducted with instructors to understand the pedagogical implications of integrating robotics in elementary settings. The data was then subjected to thematic analysis.

Instructors perceived ER as highly interactive, fostering engagement and collaboration. They saw robotics as an avenue for students to immerse themselves in computational and problem-solving tasks, which are integral for cognitive and computational skill development (Eric, Sheila, Steve, Terry, and Vince). Additionally, from the educators’ viewpoint, robotics introduced students to STEM concepts and significantly increased their CT. The hands-on nature of robotic tasks facilitates intricate problem-solving, data analysis, and computational modeling, bridging the gap between theoretical knowledge and practical application (Chris, Sandra, Eric, and Shawn).

Grounded in Papert’s (1980) constructionism theory, ER provided a hands-on learning experience, fostering a connection between knowledge construction and tangible outputs. As Papert (1980) contended, knowledge is not merely transmitted by instructors but is actively constructed by learners. ER emulated the four pillars of constructionism—learning by doing, object recognition, influential ideas, and self-reflection, which further underlined the inherent pedagogical value of ER (Bers et al., 2002; Lye & Koh, 2014; Scogin et al., 2017; Slangen et al., 2011). The implication of this pedagogical shift will position educators as knowledge facilitators. When instructors were facilitators, the scenarios further emphasized the importance of experiential learning (Kolb, 1984; Scogin et al., 2017).

Recommendation for Practical Application

Shift Toward a Facilitative Teaching Approach

Adopting Papert's (1980) constructionism theory would require a shift in teaching dynamics. Rather than being primary knowledge transmitters, educators in the elementary setting would need to reposition themselves as facilitators. This new role involves guiding students through hands-on activities, allowing students to build, experiment, and reflect upon their experiences (Papert, 1980). This approach promoted a more student-centric learning environment where learners actively engage in the knowledge-construction process. This transition may require significant professional development for educators to understand and adopt this facilitative role effectively.

Interdisciplinary Curricular Integration

The use of ER in elementary settings provided opportunities for interdisciplinary curricular integration. As Slangen et al. (2011) suggested, the principles learned from ER can be applied across various curriculum areas, including mathematics, science, engineering, and computer science. The goal is to integrate different perspectives from multiple disciplines to advance fundamental understanding and solve complex problems. This integrated approach can make learning more holistic, allowing students to see different subjects' interconnectedness and relevance in the real world. Educational leaders may need to consider restructuring curriculum planning sessions to encourage more interdisciplinary collaboration.

Increase Experiential Learning Environments

The emphasis on “learning by doing” underscores the need for elementary settings to foster experiential learning environments. According to Kong (2021), students who engaged in hands-on activities reported enhanced learning engagement and better learning outcomes. To implement this, elementary schools might need to invest in resources, such as robotics kits and collaborative workspace areas, to support experiential learning. Furthermore, curricular activities may need to be reevaluated to ensure they provide ample opportunities for students to tinker, troubleshoot, and problem-solve, as Moye et al. (2017) highlighted.

Recommendations for Future Research

Drawing from the current research of instructors’ perspectives on ER and CT, a few options for future studies emerged. First, as Sheila (a study participant) suggested, a longitudinal study could provide data for the long-term ramifications of elementary students’ engagement with robotics on their inclination toward STEM careers. A longitudinal assessment could shed light on the ways to promote STEM careers. A study that examines students’ viewpoints and experiences will provide data regarding the influence of ER on learning. Simultaneously, a comparative evaluation of traditional pedagogies against robotics-infused teaching methods could offer insights into the effectiveness of each in cultivating CT abilities in elementary learners.

A consideration for future research in the field of ER and developing CT, with a gender-related focus, could explore how to design robotics curricula and activities that are inclusive and appealing to students of all genders. This might involve investigating which types of projects, challenges, or themes are more likely to engage both boys and girls in CT through robotics. Additionally, as ER strives to be inclusive, there could be research to increase the engagement of students who struggle in math and science. A study could conduct a comprehensive needs assessment to understand the specific challenges and barriers faced by students with weaker math and science skills in ER. The implementation of these recommendations is not just a step but a significant leap toward the optimal use of ER in elementary schools. By doing so, educators are not merely introducing students to a technological tool; they are cultivating an environment where critical and CT can flourish. This foundation is crucial as these skills are no longer optional but essential in the rapidly evolving 21st-century landscape. With the right strategies in place, educators can ensure that students are not only consumers of technology but also innovators, ready to face the complexities and challenges of the modern world.

Conclusion

In conclusion, this study not only reaffirmed the pedagogical potential of ER in fostering critical and CT among elementary students but also underscored the foundational pillars of constructionism as defined by Papert (1980) and elaborated upon by later scholars. Whereas prior research has hinted at the individual components of CT, this study holistically emphasized the relationship between hands-on learning and computational thought processes. When engaged with ER rooted in constructionist principles, the findings suggested that students could effectively transfer and apply learned principles across various academic disciplines, from mathematics to engineering (Slangen et al., 2011). Consequently, this research makes a strong argument for the expanded use of ER in schools, highlighting its significance in promoting active, hands-on learning and enhancing critical and CT skills.

Chapter Summary

Recent research has spotlighted the importance of CT in K–12 educational settings due to its potential to bolster academic performance and prepare students for a digitally infused future

(Bers & Sullivan, 2019; Chevalier et al., 2020; Wing, 2011). The state of Texas, with identified deficits in student math scores, pinpointed CT as a focal area for improvement. A burgeoning approach to tackling this gap is through ER, which positively correlates with CT development (Angeli & Valanides, 2020; Bers & Sullivan, 2019).

References

Acar, D., Tertemiz, N., & Taşdemir, A. (2018, March). The effects of STEM training on the academic achievement of 4th graders in science and mathematics and their views on STEM training teachers. *International Electronic Journal of Elementary Education*, *10*(4), 505–513. https://doi.org/10.26822/iejee.2018438141

Aggarwal, R. (2011, June). Developing a global mindset: Integrating demographics, sustainability, technology, and globalization. *Journal of Teaching in International Business*, *22*(1), 51–69. https://doi.org/10.1080/08975930.2011.585920

Allen, D., & Oliver-Hoyo, M. T. (2006). The use of triangulation methods in qualitative educational research. *Journal of College Science Teaching*, *35*(4), 42–47. https://eric.ed.gov/?id=EJ752577

Anderson, V. (2017). Criteria for evaluating qualitative research. *Human Resource Development Quarterly*, *28*(2), 125–133. https://doi.org/10.1002/hrdq.21282

Anfara, V. A., Jr., Brown, K. M., & Mangione, T. L. (2002). Qualitative research on stage: Making the research process more public. *Educational Researcher*, *31*(7), 28–38. https://doi.org/10.3102/0013189X031007028

Angeli, C., & Valanides, N. (2020, April). Developing young children's computational thinking with educational robotics: An interaction effect between gender and scaffolding strategy. *Computers in Human Behavior*, *105*. https://doi.org/10.1016/j.chb.2019.03.018

Anney, V. (2014). Ensuring the quality of the findings of qualitative research: Looking at trustworthiness criteria. *Journal of Emerging Trends in Educational Research and Policy Studies*, *5*(2), 272–281. https://www.scirp.org/%28S%28351jmbntvnsjt1aadkposzje%29%29/reference/referencespapers.aspx?referenceid=3077301

Arfé, B., Vardanega, T., & Ronconi, L. (2020). The effects of coding on children's planning and inhibition skills. *Computers & Education, 148,* Article 103807. https://psycnet.apa.org/record/2020-08580-001

Atkinson, P., & Silverman, D. (1997). Kundera's immortality: The interview society and the invention of the self. *Qualitative Inquiry, 3*(3), 304–325. https://doi.org/10.1177/107780049700300304

Avcu, Y. E., & Ayverdi, L. (2020). Examination of the computer programming self-efficacy's prediction towards the computational thinking skills of the gifted and talented students. *International Journal of Educational Methodology*, *6*(2), 259–270. https://files.eric.ed.gov/fulltext/EJ1254830.pdf

Barak, M., & Assal, M. (2018, March). Robotics and STEM learning: Students' achievements in assignments according to the P3 Task Taxonomy—practice, problem solving, and projects. *International Journal of Technology and Design Education*, *28*(1), 121–144. https://eric.ed.gov/?id=EJ1170043

Baroutsis, A., White, S. L., Ferdinands, E., Lambert, E., & Goldsmith, W. (2019). Computational thinking as a foundation for coding: Developing student engagement and learning. *Australian Primary Mathematics Classroom*, *24*(2), 11–15. https://eric.ed.gov/?id=EJ1289378

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, *72,* 145–157. https://psycnet.apa.org/doi/10.1016/j.compedu.2013.10.020

Bers, M. U., Ponte, I., J. C., Viera, A., & Schenker, J. (2002). Teachers as designers: Integrating robotics in early childhood education. *Information Technology in Childhood Education Annual*, *2002*(1), 123–145. https://eric.ed.gov/?id=EJ823468

Bers, M. U., & Sullivan, A. (2019). Computer science education in early childhood: The case of ScratchJr. *Journal of Information Technology Education: Innovations in Practice*, *18*, 113–138. https://www.jite.org/documents/Vol18/JITEv18IIPp113-138Bers5788.pdf

Blikstein, P. (2018). Maker movement in education: History and prospects. In M. J. de Vries (Ed.), *Handbook of technology education* (pp. 419–437). Springer. https://doi.org/10.1007/978-3-319-44687-5_33

Bloomberg, L. D., & Volpe, M. (2008). Completing your qualitative dissertation: A roadmap from beginning to end. SAGE Publications.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brennan, K., & Resnick, M. (2012, April). *New frameworks for studying and assessing the development of computational thinking*. Paper presented at the 2012 Annual Meeting at the American Educational Research Association, Vancouver, Canada (pp. 1–25). https://web.media.mit.edu/~kbrennan/files/Brennan_Resnick_AERA2012_CT.pdf

Byrne, J. R., Girvan, C., & Clayson, J. (2021, May). Constructionism moving forward. *British Journal of Educational Technology*, *52*(3), 965–968. https://bera-journals.onlinelibrary.wiley.com/doi/epdf/10.1111/bjet.13094

Caelli, K., Ray, L., & Mill, J. (2003). 'Clear as mud': Toward greater clarity in generic qualitative research. *International Journal of Qualitative Methods*, *2*(2), 1–13. https://doi.org/10.1177/160940690300200201

Cannon-Ruffo, C. M. (2020). *The efficacy of educational robotics in an integrated STEM elementary curriculum* [Doctoral dissertation, Northern Illinois University]. Graduate Research Theses & Dissertations. https://huskiecommons.lib.niu.edu/cgi/viewcontent.cgi?article=7893&context=allgraduate-thesesdissertations

Carlson, J. A. (2010). Avoiding traps in member checking. *Qualitative Report*, *15*(5), 1102–1113. http://www.nova.edu/ssss/QR/QR15-5/carlson.pdf

Castro, E., Cecchi, F., Valente, M., Buselli, E., Salvini, P., & Dario, P. (2018, December). Can educational robotics introduce young children to robotics and how can we measure it? *Journal of Computer Assisted Learning*, *34*(6), 970–977. https://doi.org/10.1111/jcal.12304

Chevalier, M., Giang, C., Piatti, A., & Mondada, F. (2020). Fostering computational thinking through educational robotics: a model for creative computational problem solving. *International Journal of STEM Education*, *7*(1), 1–18. https://doi.org/10.1186/s40594-020-00238-z

Chiazzese, G., Arrigo, M., Chifari, A., Lonati, V., & Tosto, C. (2019). Educational robotics in primary school: Measuring the development of computational thinking skills with the Bebras task. *Informatics*, *6*(4), 1–12. https://doi.org/10.3390/informatics6040043

Ching, Y.-H., Hsu, Y.-C., & Baldwin, S. (2018, April). Developing computational thinking with educational technologies for young learners. *TechTrends: Linking Research & Practice to Improve Learning*, *62*(6), 563–573. https://doi.org/10.1007/s11528-018-0292-7

Çınar, M., & Tüzün, H. (2021, April). Comparison of object-oriented and robot programming activities: The effects of programming modality on student achievement, abstraction, problem solving, and motivation. *Journal of Computer Assisted Learning*, *37*(2), 370–386. https://doi.org/10.1111/jcal.12495

Cobb, P., & Gravemeijer, K. (2014). Experimenting to support and understand learning processes. In A. E. Kelly, R. A. Lesh, & J. Y. Baek (Eds.), *Handbook of design research methods in education* (pp. 68–95). Routledge.

Creswell, J. W. (2013). Qualitative inquiry and research design: Choosing among five approaches. SAGE Publications.

Creswell, J. W. (2014). *Research design* (4th ed.). SAGE Publications.

Creswell, J. W. (2015). A concise introduction to mixed methods research. SAGE Publications.

Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, quantitative, and mixed methods approaches. SAGE Publications.

Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry. *Theory into Practice*, *39*(3), 124–130. https://www.jstor.org/stable/1477543

Cruz, I. L. J. (2019). *Impact of educational robotics in promoting critical thinking skills of middle school students* [Doctoral dissertation, Southern University and Agricultural and Mechanical College]. ProQuest Dissertations & Theses Global. https://eric.ed.gov/?id=ED604701

Da Cruz Alves, N., Gresse Von Wangenheim, C., & Hauck, J. C. R. (2019). Approaches to assess computational thinking competences based on code analysis in K-12 education: A systematic mapping study. *Informatics in Education*, *18*(1), 17–39. https://files.eric.ed.gov/fulltext/EJ1212844.pdf

Doyle, S. (2007). Member checking with older women: A framework for negotiating meaning. *Health Care for Women International*, *28*(10), 888–908. https://pubmed.ncbi.nlm.nih.gov/17987459/

Durak, H. Y., & Saritepeci, M. (2018, January). Analysis of the relation between computational thinking skills and various variables with the structural equation model. *Computers & Education*, *116*, 191–202. https://www.sciencedirect.com/science/article/abs/pii/S0360131517302087

Durak, H. Y., Yilmaz, F. G. K., & Yilmaz, R. (2019, April). Computational thinking, programming self-efficacy, problem solving and experiences in the programming process conducted with robotic activities. *Contemporary Educational Technology, 10*(2), 173–197. https://doi.org/10.30935/cet.554493

Ezzy, D. (2010). Qualitative interviewing as an embodied emotional performance. *Qualitative Inquiry*, *16*(3), 163–170. https://doi.org/10.1177/1077800409351970

Fidai, A., Capraro, M. M., & Capraro, R. M. (2020, December). “Scratch”-ing computational thinking with Arduino: A meta-analysis. *Thinking Skills and Creativity, 38*. https://doi.org/10.1016/j.tsc.2020.100726

Glesne, C. (2016). Becoming a qualitative researcher: An introduction (5th ed.). Pearson.

Grover, S., & Pea, R. (2013). Computational thinking in K–12: A review of the state of the field. *Educational Researcher, 42*(1), 38–43. https://doi.org/10.3102/0013189X12463051

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Communication and Technology: A Journal of Theory, Research, and Development*, *29*(2), 75–91. https://link.springer.com/article/10.1007/BF02766777

Guetterman, T. C. (2015). Descriptions of sampling practices within five approaches to qualitative research in education and the health sciences. *Forum: Qualitative Social Research*, *16*(2), 389–411. https://doi.org/10.17169/fqs-16.2.2290

Günbatar, M. S. (2020). Computational thinking skills, programming self-efficacies and programming attitudes of the students. *International Journal of Computer Science Education in Schools*, *4*(2), 1–9. https://doi.org/10.21585/ijcses.v4i2.96

Herr, K., & Anderson, G. (2015). *The action research dissertation*. SAGE Publications.

Holbert, N. (2016). The powerful ideas of making: Building beyond the curriculum. *Journal of Innovation and Entrepreneurship*, *5*(1), 1–7. https://innovation-entrepreneurship.springeropen.com/articles/10.1186/s13731-016-0058-4

Holland, D., & Leander, K. (2004, June). Ethnographic studies of positioning and subjectivity: An introduction. *Ethos*, *32*(2), 127–139. https://www.jstor.org/stable/3651830

Huang, K. H., Yang, T. M., & Cheng, C. C. (2013). Engineering to see and move: Teaching computer programming with flowcharts vs. LEGO Robots. *International Journal of Emerging Technologies in Learning*, *8*(4), 23–26. https://online-journals.org/index.php/i-jet/article/view/2943

Jamal, N. N., Jawawi, D. N. A., Hassan, R., & Mamat, R. (2021). Conceptual model of learning computational thinking through educational robotic. *International Journal of Emerging Technologies in Learning*, *16*(15), 91–106. https://online-journals.org/index.php/i-jet/article/view/24257

Julià, C., & Antolí, J. O. (2016). Spatial ability learning through educational robotics. *International Journal of Technology and Design Education*, *26*(2), 185–203. https://doi.org/10.1007/s10798-015-9307-2

Jung, S. E., & Won, E.-S. (2018). Systematic review of research trends in robotics education for young children. *Sustainability*, *10*(4), 905–929. https://www.mdpi.com/2071-1050/10/4/905

Kafai, Y. B., & Burke, Q. (2014). Connected code: Why children need to learn programming. MIT Press.

Kaufman, R., & Guerra-Lopez, I. (2013, February). *Needs assessment for organizational success*. Association for Talent Development.

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal*, *41*(4), 245–255. https://psycnet.apa.org/doi/10.1007/s10643-012-0554-5

Kelter, J., Peel, A., Bain, C., Anton, G., Dabholkar, S., Horn, M. S., & Wilensky, U. (2021, May). Constructionist co-design: A dual approach to curriculum and professional development. *British Journal of Educational Technology*, *52*(3), 1043–1059. https://doi.org/10.1111/bjet.13084

Kim, M. H., Bousselot, T. E., & Ahmed, S. F. (2021). Executive functions and science achievement during the five-to-seven-year shift. *Developmental Psychology*, *57*(12), 2119–2133. https://doi.apa.org/doiLanding?doi=10.1037%2Fdev0001261

Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Prentice Hall.

Kong, S.-C., & Wang, Y.-Q. (2019). Nurture interest-driven creators in programmable robotics education: An empirical investigation in primary school settings. *Research and Practice in Technology Enhanced Learning*, *14*(1), 1–19. https://doi.org/10.1186/s41039-019-0116-1

Kong, Y. (2021, October). The role of experiential learning on students' motivation and classroom engagement. *Frontiers in Psychology*, *12*, 1–4. https://www.frontiersin.org/articles/10.3389/fpsyg.2021.771272/full

Kotsopoulos, D., Floyd, L., Dickson, B. A., Nelson, V., & Makosz, S. (2021). Noticing and naming computational thinking during play. *Early Childhood Education Journal*, *50*, 699–708. https://link.springer.com/article/10.1007/s10643-021-01188-z

LaForce, M., Zuo, H., Ferris, K., & Noble, E. (2019). Revisiting race and gender differences in STEM: Can inclusive STEM high schools reduce gaps? *European Journal of STEM Education*, *4*(1), 1–15. https://files.eric.ed.gov/fulltext/EJ1222747.pdf

Leavy, P. (2017). Design research: Quantitative, qualitative, mixed methods, art-based, and community-based participatory research approaches. Guilford Press.

Lego Education. (2023). *LEGO® MINDSTORMS® education EV3 core set*. https://education.lego.com/en-us/products/lego-mindstorms-education-ev3-core-set/5003400/#lego-mindstorms-education-ev3

Leonard, J., Barnes-Johnson, J., Mitchell, M., Unertl, A., Stubbe, C. R., & Ingraham, L. (2017). *Developing teachers' computational thinking belief and engineering practices through game design and robotics*. In E. Galindo & J. Newton (Eds.), Proceedings of the 39th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education. Indianapolis, Indiana. https://stelar.edc.org/publications/developing-teachers-computational-thinking-beliefs-and-engineering-practices-through

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. SAGE Publications.

Locke, L. F., Silvermen, S. J., & Spirdus, W. W. (2010). *Reading and understanding research* (3rd ed.). SAGE Publications.

Lye, S. Y., & Koh, J. H. L. (2014). Review on teaching and learning of computational thinking through programming: What is next for K-12? *Computers in Human Behavior*, *41*, 51–61. https://doi.org/10.1016/j.chb.2014.09.012

Makri, K., Daskolia, M., & Kynigos, C. (2015). Authors' response: Seeking "power" in powerful ideas, systems thinking and affective aspects of learning. *Constructivist Foundations*, *10*(3), 401–404. https://constructivist.info/10/3/401

Marshall, C., & Rossman, G. (2016). *Designing qualitative research* (6th ed.). SAGE Publications.

Mason, M. (2010). Sample size and saturation in Ph.D. studies using qualitative interviews. *Forum: Qualitative Social Research*, *11*(3), 1–20. https://doi.org/10.17169/fqs-11.3.1428

Maxwell, J. (2012). Qualitative research design: An interactive approach. SAGE Publications.

Mayoral-Rodríguez, S., Timoneda-Gallart, C., & Pérez-Álvarez, F. (2018). Effectiveness of experiential learning in improving cognitive planning and its impact on problem solving and mathematics performance. *Culture and Education*, *30*(2), 308–337. https://www.tandfonline.com/doi/abs/10.1080/11356405.2018.1457609

Merino-Armero, J. M., González-Calero, J. A., & Cózar-Gutiérrez, R. (2020). Computational thinking in K-12 education. An insight through meta-analysis. *Journal of Research on Technology in Education*, *54*(3), 410–437. https://doi.org/10.1080/15391523.2020.1870250

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. Jossey-Bass.

Merriam, S. B., & Tisdell, E. J. (2016). *Qualitative research : A guide to design and implementation* (4th ed.). Jossey-Bass.

Mertler, C. A. (2017). *Action research: Improving schools and empowering educators* (5th ed.). SAGE Publications.

Mills, G. E., & Gay, L. R. (2016). *Educational research: Competencies for analysis and applications* (11 ed). Pearson.

Min, S. H., & Kim, M. K. (2020, December). Developing children's computational thinking through physical computing lessons. *International Electronic Journal of Elementary Education*, *13*(2), 183–198. https://doi.org/10.26822/iejee.2021.183

Mizanoor Rahman, S. M. (2021). Assessing and benchmarking learning outcomes of robotics-enabled STEM education. *Education Sciences*, *11*(2), 84–109. https://doi.org/10.3390/educsci11020084

Morado, M. F., Melo, A. E., & Jarman, A. (2021, May). Learning by making: A framework to revisit practices in a constructionist learning environment. *British Journal of Educational Technology*, *52*(3), 1093–1115. https://doi.org/10.1111/bjet.13083

Moraiti, I., Fotoglou, A., & Drigas, A. (2022). Coding with block programming languages in educational robotics and mobiles, improve problem solving, creativity & critical thinking skills. *International Journal of Interactive Mobile Technologies, 16*(20), 59–78. https://online-journals.org/index.php/i-jim/article/view/34247

Moye, J. J., Dugger, W. E., Jr., & Starkweather, K. N. (2017, November). Learn better by doing study: Fourth-year results. *Technology and Engineering Teacher*, *77*(3), 32–38. https://eric.ed.gov/?id=EJ1159144

Munn, C. A. (2021, July). A qualitative study exploring robots as a potential classroom tool for teaching computational thinking within a sixth-grade class. *Journal of Computers in Mathematics and Science Teaching*, *40*(3), 229–264. https://eric.ed.gov/?id=EJ1313937

Muñoz-Repiso, A. G.-V., & Caballero-González, Y.-A. (2019). Robotics to develop computational thinking in early childhood education. *Comunicar: Media Education Research Journal*, *27*(59), 63–72. https://eric.ed.gov/?id=EJ1211742

National Center for Women and Technology. (2020). *NCWIT scoreboard: A report on the status of women in information technology*. https://www.issuelab.org/resources/18105/18105.pdf

National Science Board. (2014). *Science and engineering indicators 2014*. National Science Foundation. https://www.nsf.gov/statistics/seind14/

Negrini, L., & Giang, C. (2019). How do pupils perceive educational robotics as a tool to improve their 21st century skills? *Journal of E-Learning and Knowledge Society*, *15*(2), 77–87. https://www.je-lks.org/ojs/index.php/Je-LKS_EN/article/view/1135008

Nic Réamoinn, M. S., & Devitt, A. (2019). Children's perspectives on the use of robotics for second language learning in the early years of primary education: A pilot study. In F. Meunier, J. Van de Vyver, L. Bradley, & S. Thouësny (Eds.), *CALL and complexity– short papers from EUROCALL 2019* (pp. 321–326). Research-Publishing.net. https://files.eric.ed.gov/fulltext/ED600975.pdf

Noh, J., & Lee, J. (2020). Effects of robotics programming on the computational thinking and creativity of elementary school students. *Educational Technology Research and Development*, *68*(1), 463–484. https://doi.org/10.1007/s11423-019-09708-w

Nugent, G., Barker, B., Grandgenett, N., & Adamchuk, V. I. (2010). Impact of robotics and geospatial technology interventions on youth STEM learning and attitudes. *Journal of Research on Technology in Education*, *42*(4), 391–408. https://files.eric.ed.gov/fulltext/EJ895054.pdf

Papanastasiou, G., Drigas, A., Skianis, C., Lytras, M., & Papanastasiou, E. (2019). Virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills. *Virtual Reality*, *23*(4), 425–436. https://doi.org/10.1007/s10055-018-0363-2

Papavlasopoulou, S., Sharma, K., & Giannakos, M. N. (2020, April). Coding activities for children: Coupling eye-tracking with qualitative data to investigate gender differences. *Computers in Human Behavior*, *105*. https://doi.org/10.1016/j.chb.2019.03.003

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books.

Papert, S. (2000, July). What's the big idea? Toward a pedagogy of idea power. *IBM Systems Journal*, *39*(3/4), 720–729. https://doi.org/10.1147/sj.393.0720

Park, J. (2015, January). Effect of robotics-enhanced inquiry-based learning in elementary science education. *Journal of Computers in Mathematics and Science Teaching*, *34*(1), 71–95. https://eric.ed.gov/?id=EJ1048464

Patton, M. Q. (2015). *Qualitative research & evaluation methods: Integrating theory and practice*. SAGE Publications.

Pitney, W. A. (2004). Strategies for establishing trustworthiness in qualitative research. *International Journal of Athletic Therapy and Training*, *9*(1), 26–28. https://journals.humankinetics.com/view/journals/ijatt/9/1/article-p26.xml

Reich-Stiebert, N., Eyssel, F., & Hohnemann, C. (2020). Exploring university students' preferences for educational robot design by means of a user-centered design approach. *International Journal of Social Robotics*, *12*(1), 227–237. https://doi.org/10.1007/s12369-019-00554-7

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., Millner, A., Rosenbaum, E., Silver, J., Silverman, B., & Kafai, Y. (2009, November). Scratch: Programming for all. *Communications of the ACM*, *52*(11), 60–67. https://web.media.mit.edu/~mres/papers/Scratch-CACM-final.pdf

Roulston, K., & Choi, M. (2018). Qualitative interviews. In U. Flick (Ed.), *The SAGE handbook of qualitative data collection* (pp. 233–249). SAGE Publications.

Sáez-López, J.-M., Sevillano-García, M.-L., & Vazquez-Cano, E. (2019, January). The effect of programming on primary school students' mathematical and scientific understanding: Educational use of mBot. *Educational Technology Research and Development*, *67*(6), 1405–1425. https://doi.org/10.1007/s11423-019-09648-5

Saldana, J., & Omasta, M. (2018). *Qualitative research: Analyzing life*. SAGE Publications.

Scogin, S. C., Kruger, C. J., Jekkals, R. E., & Steinfeldt, C. (2017, March). Learning by experience in a standardized testing culture: Investigation of a middle school experiential learning program. *Journal of Experiential Education*, *40*(1), 39–47. https://eric.ed.gov/?id=EJ1129193

Seiter, L., & Foreman, B. (2013). *Modeling the learning progressions of computational thinking of primary grade students*. Proceedings of the Ninth Annual International ACM Conference on International Computing Education Research, (pp. 59–66). San Diego, California. https://doi.org/10.1145/2493394.2493403

Shenton, A. K. (2004, July). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information*, *22*(2), 63–75. https://content.iospress.com/articles/education-for-information/efi00778

Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017, November). Demystifying computational thinking. *Educational Research Review*, *22*, 142–158. https://doi.org/10.1016/j.edurev.2017.09.003

Sisman, B., Kucuk, S., & Ozcan, N. (2022, August). Collaborative behavioural patterns of elementary school students working on a robotics project. *Journal of Computer Assisted Learning*, *38*(4), 1018–1032. https://doi.org/10.1111/jcal.12659

Slangen, L., Van Keulen, H., & Gravemeijer, K. (2011). What pupils can learn from working with robotic direct manipulation environments. *International Journal of Technology and Design Education*, *21*, 449–469. https://link.springer.com/article/10.1007/s10798-010-9130-8#citeas

Sohn, I. (2018). The future of work in the United States: Projections of occupational employment in 2026. *Foresight: International Journal of Applied Forecasting*, *49*, 33–38. https://ideas.repec.org/a/for/ijafaa/y2018i49p33-38.html

Stewart, W. H., Baek, Y., Kwid, G., & Taylor, K. (2021). Exploring factors that influence computational thinking skills in elementary students' collaborative robotics. *Journal of Educational Computing Research*, *59*(6), 1208–1239. https://doi.org/10.1177/0735633121992479

Strawhacker, A., Sullivan, A., Verish, C., Bers, M. U., & Shaer, O. (2018). Enhancing children's interest and knowledge in bioengineering. *Journal of Information Technology Education, 17*, 55–81. https://eric.ed.gov/?id=EJ1176129

Stringer, E. T. (2007). *Action research* (3rd ed.). SAGE Publications.

Sullivan, A., & Bers, M. U. (2016a). Robotics in the early childhood classroom: Learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. *International Journal of Technology and Design Education*, *26,* 3–20. https://doi.org/10.1007/s10798-015-9304-5

Sullivan, A., & Bers, M. U. (2016b). Girls, boys, and bots: Gender differences in young children's performance on robotics and programming tasks. *Journal of Information Technology Education: Innovations in Practice, 15*, 145–165. https://eric.ed.gov/?id=EJ1113035

Sullivan, A., & Bers, M. U. (2019). Investigating the use of robotics to increase girls' interest in engineering during early elementary school. *International Journal of Technology and Design Education*, *29*, 1033–1051. https://link.springer.com/article/10.1007/s10798-018-9483-y

Tang, X., Yin, Y., Lin, Q., Hadad, R., & Zhai, X. (2020, April). Assessing computational thinking: A systematic review of empirical studies. *Computers and Education*, *148*, 1–22. https://doi.org/10.1016/j.compedu.2019.103798

Taylor, K., & Baek, Y. (2018). Collaborative robotics, more than just working in groups. *Journal of Educational Computing Research*, *56*(7), 979–1004. https://journals.sagepub.com/doi/10.1177/0735633117731382

Terrell, S. R. (2016). *Writing a proposal for your dissertation*. Guilford Press.

Toh, L. P. E., Causo, A., Tzuo, P.-W., Chen, I.-M., & Yeo, S. H. (2016). A review on the use of robots in education and young children. *Journal of Educational Technology and Society*, *19*(2), 148–163. https://www.jstor.org/stable/jeductechsoci.19.2.148

Tsai, M.-J., Wang, C.-Y., & Hsu, P.-F. (2019). Developing the computer programming self-efficacy scale for computer literacy education. *Journal of Educational Computing Research*, *56*(8), 1345–1360. https://doi.org/10.1177/0735633117746747

Ucgul, M., & Cagiltay, K. (2014). Design and development issues for educational robotics training camps. *International Journal of Technology & Design Education*, *24*(2), 203–222. https://doi.org/10.1007/s10798-013-9253-9

Vandenberg, J., Rachmatullahb, A., Lynch, C. Boyer, K. E., & Wiebe, E. (2021, September). Interaction effects of race and gender in elementary CS attitudes: A validation and cross-sectional study. *International Journal of Child-Computer Interaction*, *29*(C), 1–11. https://dl.acm.org/doi/10.1016/j.ijcci.2021.100293

Vex Robotics. (2023). *IQ: Any Educator can teach STEM with VEX*. https://www.vexrobotics.com/iq

Wing, J. M. (2006, March). Computational thinking. *Communications of the ACM*, *49*(3), 33–35. http://www.cs.cmu.edu/~./15110-s13/Wing06-ct.pdf

Wing, J. M. (2011). *Research notebook: Computational thinking—what and why*? Link Magazine: Carnegie Mellon University, School of Computer Science. https://www.cs.cmu.edu/link/research-notebook-computational-thinking-what-and-why

Wolcott, H. F. (2009). *Writing up qualitative research* (3rd ed.). SAGE Publications.

Yin, R. K. (2003). *Case study research: Design and methods* (3rd ed.). SAGE Publications.

Zhang, Y., Luo, R., Zhu, Y., & Yin, Y. (2021). Educational robots improve K-12 students' computational thinking and STEM attitudes: Systematic review. *Journal of Educational Computing Research*, *59*(7), 1450–1481. https://doi.org/10.1177/0735633121994070

Zhong, B., & Li, T. (2020). Can pair learning improve students' troubleshooting performance in robotics education? *Journal of Educational Computing Research*, *58*(1), 220–248. https://doi.org/10.1177/0735633119829191

Appendix A: Social Media Post

Looking for a few good men and women to participate in a descriptive study of Educational Robotics and Computational Thinking in Elementary School Students.

The qualifying criteria include:

1. Educational Robotics Teacher of Elementary Students in TEXAS.
2. At least 18 years old.
3. Willingness to participate in a 30–45-minute interview.

Follow the link below for details.

(The link will be Appendix A)

Appendix B: The Google Document Flyer

I am a doctoral student in educational leadership with a focus on emerging technology at Abilene Christian University, located in Abilene, Texas, and my doctoral dissertation will explore the impact of educational robotics and computational thinking on elementary school students.

My data collection will include:

1. Robotics instructor’s lesson outlines.
2. Robotics instructor’s interview (45–60 minutes via Zoom).
3. Pictures or student work from the submitted lesson outline.

The goal of the study is to explore computational thinking through instructor-interpreted experiences or educational robotics activities. The method is a qualitative descriptive study. A coding system will be used to identify the collected data to preserve the confidentiality of all of the participants. Participants may discontinue participation in this study at any time. There will be no identifying information about the district, school, or students in the study’s findings. At the conclusion of the study, the results will be made available to you.

The study participants are required to meet the following criteria: (a) above the age of 18 and (b) provide formal or informal robotics instruction in an elementary school setting.

If you would be interested in participating in the described study, please complete the information below, and I will email study details and a consent form.

________ Yes, I am above the age of 18

________ Yes, I have a working knowledge of the educational robotics platform, and I provide formal or informal robotics instruction in an elementary school setting in the state of Texas.

Name ________________________________ Email ________________________________

Please complete this form; information will be forwarded to xxxxx@gmail.com.

Questions or concerns, please contact Sonia Jordan at xxx-xxx-xxxx or xxxxx@gmail.com.

Appendix C: Survey Questions for Student Work

Describe the student assignment.

Did students understand the activity?

Did the student work independently or collaboratively?

Describe the classroom environment.

What cogitative skills are applied?

Describe (male and female) student’s engagement during the assignment.

Describe the instructor’s role in the student’s assignment (active, passive, authoritative, facilitator vs. dictator).

Describe the demonstration of computational thinking principles during the assignment, if any.

Appendix D: Semistructured Interview Questions

This is a semistructured interview, meaning these questions should be used as a guide, but other relevant topics can be addressed. Participants may skip any questions they do not feel comfortable answering. Interviewers may skip/add/adapt any questions as needed. These questions are used as a starting point for conversation. Answers will be used to direct any relevant follow-up questions and prompts.

What is the goal of robotics instruction?

How do male and female students engage in educational robotics (similarities and differences)?

Elaborate on whether you believe educational robotics help students develop computational thinking skills.

In addition to computational thinking, what benefits (if any) does educational robotics have for students, such as teamwork, endurance, and curiosity?

What computational thinking vocabulary do students use most often?

What computational thinking strategies are used by the students?

Closing: Thank you for agreeing to participate in this study. The information you provided will only be used as data in the research study. No student identification information will be used, and the data will be reported as truthfully as possible. The goal of this semistructured interview is to obtain data that describes your observations and perceptions of the impact of educational robotics on the development of computational thinking on third and fourth grade students.

Appendix E: Letter to Robotics Instructor

Date: ___________, 2023

Dear _____________________:

I am a doctoral student in educational leadership with a focus on emerging technology at Abilene Christian University, located in Abilene, Texas. I am conducting my dissertation research under the direction of Program Director Dr. Karen Maxwell, Dissertation Manager Dr. Dana McMichael, and dissertation chair Dr. Christie Bledsoe. My doctoral dissertation will explore the impact of educational robotics and computational thinking on elementary school students. The goal of the study is to explore computational thinking through instructors' interpreted experiences or educational robotics activity. The qualitative study will be using deductive thematic analysis. A coding system will be used to identify the collected data to preserve the confidentiality of all of the participants. Participants may discontinue participation in this study at any time. There will be no identifying information about the district, school, or students in the study's findings. At the conclusion of the study, results will be made available to you.

If you have questions or concerns about this study, please contact Sonia Jordan at xxx-xxx-xxxx, xxxx@acu.edu; Dr. Dana McMichael at xxxx@acu.edu, or Dr. Christie Bledsoe, dissertations committee chair xxxx@acu.edu.

Sincerely,

Sonia Jordan

If you are willing to participate in this study, please follow the link below.

____ I will participate in the study. (Link to Appendix E)