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Computational thinking integrated into the English language curriculum in primary education: A systematic review

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Abstract
Computational thinking (CT) is valued as a thinking process that is required to adapt to the development of curriculum in primary education. In the context of modern information technology, English as a language subject emphasizes the necessity for changes in both learning and teaching modes. However, there is a lack of up-to-date synthesis research and a comprehensive overview surrounding CT integrated into English language curriculum learning and teaching in primary education. To address this research gap, this study conducted a systematic literature review on CT in the primary English curriculum, based on papers published from 2011 to 2021. The purpose of this review is to systematically examine and present empirical evidence on how CT can be integrated into the teaching and learning of the primary English language curriculum in educational contexts. The review was conducted based on the PRISMA 2020 statement and presents a synthesis of 32 articles. The CT-TPACK model was adopted as a lens and framework to analyze these articles. The results indicate that the relationship among CT, content knowledge of English language curriculum, pedagogy and learning knowledge, technology and resources is highlighted. Research on the integration of CT into English courses using unplugged activities is still insufficient. The research about how teachers and students use CT to support content knowledge of the English language curriculum in various educational contexts is still in its infancy.

Keywords Computational thinking · English language curriculum · Teaching and learning · Primary education

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1 Introduction

Interest in computational thinking (CT) – though innate in many cultures – has received renewed attention by the adoption of information and communication technologies. Wing (2006) emphasized that CT involves "solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science (p. 33)". CT, as a thinking skill or process, is independent of technology and refers to the use of analytic and algorithmic approaches to formulate, analyze, and solve problems for compulsory education (Bocconi et al., 2016). Moreover, CT can be identified in three interwoven macro-categories: as generic definitions, CT is defined as a thought process with computing/programming disciplines but can be independent of them; an operational-model definition that decomposes CT into a set of fundamental competences/practices, such as abstraction and generalization, which are deeply rooted in computer science and computing, but also applicable elsewhere; and definitions related to educational and curricular frameworks that inherently involve problem-solving methods inspired by computer science or applicable in computing (Román-González et al., 2017). As a driving force for curriculum integration, CT is necessary to establish an understanding of what CT is and how to integrate it into the context (So et al., 2020; Voogt et al., 2015; Yeni et al., 2022). With the integration of CT into subject curricula gradually gaining attention, some studies focused on CT in primary education, answering important questions such as "what to teach" (Garvin et al., 2019), "what to learn" (Barr & Stephenson, 2011), "how to teach" (Jacob et al., 2018) and "how to learn" (Hsu & Liang, 2021).

Researchers have attempted to integrate CT concepts into various educational levels through teaching and learning of disciplines other than STEM. Barr and Stephenson (2011) argued that not only STEM classrooms but also language arts can be integrated with CT skills to create artifacts and solve problems. More specifically, CT mainly appears in concepts (data, events, sequences) and perspectives (connecting, expressing, questioning) in language curriculum (Mueller et al., 2017). CT can be used to teach students in fields such as social studies, art, music, English (Garvin et al., 2019), and English as a second language (Jacob et al., 2018). Moreover, the integration of CT in the curriculum across different subjects can be effective in helping students and teachers improve their knowledge, skills, and attitudes in primary education (Duncan et al., 2017; Hsu et al., 2023). The policy can act as a catalyst for local authorities to provide high-quality CT teaching for primary school pupils by explicitly integrating CT objectives into curricula in core subject areas. Through the process of CT and computer coding, the English Language Arts standards of Common Core were easily embedded into the curriculum to help students solve problems (Mensing et al., 2013). To effectively implement the integration of CT and subject curriculum, it is significant to use a variety of methods and aspects to measure implementation effectiveness. Data from teacher interviews and surveys highlighted difficulties for instructors teaching in terms of their limited CT teaching competence, CT integration time, CT-specific evaluation knowledge and tools, and pedagogical understanding for meeting the instructional needs of students (Israel et al.,

2022). Based on the learning assessment of students, both plugged and unplugged approaches are used to improve their interdisciplinary learning performance in English and CT (Hsu & Liang, 2021). Future research should investigate how teachers from various disciplines integrate CT practices into their curriculum, as well as what effective methods are used to enable teachers to participate in CT to improve their knowledge, skills, and attitude (Yadav et al., 2014). However, there is still a lack of a systematic understanding of how CT contributes to various disciplines and English language curriculum teaching and learning in primary education, which is the focus of this review study.

Based on the above analysis, the English language curriculum has theoretical and practical values as an emerging field for integrating CT. Researchers would be of great interest in this field to assist educators and students in developing CT integrated into English as a native and foreign language. However, there is a research gap that needs filling to provide insights into the current state and help educators implement CT integrated into the subject curriculum effectively. Therefore, the purpose of this literature review is to identify insight into the relationship and role by systematically examining how CT can be integrated into the teaching and learning of primary English language curriculum. It expects to provide an analytical framework for CT integrated into the subject curricula to analyze the issues arising from the integration. It can be used to clarify the dimensions among CT, English language curriculum, pedagogy and learning knowledge, technology and resources. This study expects to gain a comprehensive understanding of CT integrated into the English language curriculum and provide guidance for better optimization of curriculum practices in the future. Specifically, four questions are used to drive this systematic review.

1. What are the components of CT integrated into the English language curriculum in primary education?
2. How have implementations of CT integrated into the English language curriculum been designed in primary education?
3. How to evaluate teaching and learning of CT integrated into the English language curriculum in primary education?
4. What are the results and impacts of teaching and learning of CT integrated into the English language curriculum in primary education?

2 Theoretical framework

2.1 Computational thinking (CT)

CT, as the core thinking in computer science (CS), can be used for solving problems in many fields in today's technologically advanced world. CT initially highlights its professional notion of concepts, which revolves around procedural thinking and programming (Papert, 1980; Papert & Harel, 1991a). In the context of mathematics education, Papert (1996) defined CT and pointed out the role of computers in problem-solving to

analyze problems and test solutions. It is suggested that CT supplements mathematical and engineering thinking by focusing on designing systems that aid in the resolution of complex challenges that humans confront (Wing, 2008). Additionally, Brennan and Resnick (2012) proposed key dimensions in their CT framework, including CT concepts, CT practices, and CT perspectives. In primary education, the development of CT is usually confused with a separate coding process, which is related to a real programming activity in a specific language for young people (most notably developed as MIT for Scratch) (Kakavas et al., 2019). However, some educators in the field of computer science have claimed that programming is not necessary to teach CT. Jocius et al. (2020) indicate that the value of CT depends on the way it supports complex discipline-specific and interdisciplinary understanding. This goes away from a focus on CT as an isolated concept solely associated with computer science. CT impacts research across disciplines, including the sciences and the humanities (Bundy, 2007). Therefore, CT highlights its conceptual generality and disciplinary integration. Moreover, CT supports students in selecting and utilizing relevant tools for problem-solving (Yadav et al., 2011). CT is essential for students because it cultivates creativity, critical thinking, and problem-solving in the real world (Jong et al., 2020).

Researchers have begun to focus on the notion of CT for problem solving in different educational contexts (Yadav et al., 2016; CSTA& ISTE, 2011; Lodi & Martini, 2021). This attention serves as a strategy for comprehending and actively engaging in a digital society where computers are pervasive. In different cultural backgrounds, CT can be integrated into specific subject courses to enhance the practical elements of specific subjects' teaching and learning. Barr and Stephenson (2011) defined CT as a problem-solving approach that can be applied to different subjects through CT concepts such as data collection, data analysis, data representation, problem decomposition, abstraction, algorithms & procedures, automation, parallelization, and simulation. Lu and Fletcher (2009) presented the application of CT in math, social studies, language arts, scientific group projects, and interdisciplinary subjects. Researchers have suggested an innovative teaching strategy by merging the core concepts of CT with English language learning (Parsazadeh et al., 2021; Sabitzer et al., 2018), emphasizing the interconnection of CT, language objectives, and literacy skills. Along with CT definitions development, computational literacy has developed to consider the cognitive, material, and social components of computing influenced by various disciplines (Jacob & Warschauer, 2018). CT does not require a computer to formulate solutions (Grover & Pea, 2018). This explains why CT can be adopted in primary education in both plugged (computer-based) and unplugged (without a computer) approaches (Hsu & Liang, 2021). In this study, CT is mentioned as a thinking process that is essentially about using knowledge, methods, skills, and attitudes to solve problems in life and find solutions through technology and resources in subject learning and teaching.

2.2 CT-TPACK

Previous research has increasingly emphasized the value of technological pedagogical content knowledge (TPACK) in integrating CT for teaching and learning in the curriculum. TPACK is an emerging form of knowledge that transcends three "core"

components (content, pedagogy, and technology). Specifically, content knowledge (CK) is the subject knowledge to be learned or taught. Pedagogical knowledge (PK) is a teacher's in-depth understanding of the teaching and learning process and methods. Technological knowledge (TK) is acquired traditional knowledge in this way enables people to use information technology and to develop different ways of accomplishing tasks (Mishra & Koehler, 2006). Graham (2011) proposes that technology is not only a device or tool but also a process or method to solve problems. This interaction of components generates TCK (technological content knowledge refers to the impact of technology on the practice and knowledge of specific disciplines), TPK (technological pedagogical knowledge is about technologies used in the teaching and learning contexts), PCK (pedagogical content knowledge represents the blending of content and pedagogy for effective teaching) (Koehler et al., 2013). The TPACK framework is applicable in multiple content areas (mathematics, science, social studies, etc.), and has attracted researchers' interest for its theoretical and practical significance (Koehler et al., 2013; Voogt et al., 2013). The scope (macro, mezzo, and micro level contexts) and actor (students' and teachers' inner and external contexts) dimensions are taken into consideration to improve the TPACK framework on a comprehensive understanding of context (Porras-Hernández & Salinas-Amescua, 2013). However, there is still room to further develop the TPACK model. Moreover, alternative models could guide the integration of technology in teachers' teaching activities and students' learning processes (Archambault & Barnett, 2010).

For the CT development in K-6 curriculum design, Angeli et al. (2016) proposed a conceptualization framework of $TPCK_{CT}$ to support teaching and learning. The components of the $TPCK_{CT}$ curriculum framework include content knowledge about CT, learner knowledge for CT, pedagogical knowledge for CT, technology knowledge for CT, and context knowledge for CT. At the global level, the macro context is characterized by social, political, technical, and economic conditions that impact the value and significance of incorporating CT into the school curriculum (Angeli et al., 2016). At the local community and the educational institution level, the mezzo context refers to social, cultural, political, organizational, and economic conditions established concerning the worth of CT in students' life (Angeli et al., 2016). Kong and Lai (2021) illustrated the term "TPACK" refers to the context-based integration of technology, pedagogy, and content knowledge for CT concepts, practices, and perspectives. It focuses on TCK (programming in a block-based environment), CK (knowledge of CT concepts, practices, and perspectives), and PCK (CT pedagogies, such as unplugged activities and project-based learning, that do not use programming environments) (Kong & Lai, 2021). Yadav et al. (2017) pointed out that the TPACK framework could be a helpful model for integrating CT within the subject matter and pedagogical techniques that pre-service teachers would teach in their future classrooms. Kale et al., (2018, p.575) state that teaching CT should "entail the knowledge of using computational thinking tools (technology), knowing which instructional strategies to use to teach computational thinking and the subject matter (pedagogy), and understanding of computational thinking and the subject matter (content)". Mouza et al. (2017, p.69) proposed the curriculum cases which representation of TPACK-CT

in various subject content areas, such as "social studies (e.g., development of historical timelines), science (e.g., the life cycle of a butterfly), math (e.g., problem-solving) and English (e.g., sequencing events in a story)". This research is based on the CT-TPACK model as an outline to develop a conceptual model to identify that CT can be integrated into the English language curriculum supported by technology and resources to meet teaching and learning requirements. The conceptual framework was finally conducted based on selected studies analysis for integrating components between CT (cognitive knowledge, practices and skills, attitudes and perspectives), English language curriculum (English language content, interdisciplinary content), pedagogy and learning knowledge (curriculum implementation design and evaluation), technology and resources (plugged resources, unplugged resources, internal resources, external resources) (see Fig. 1).

3 Methods

3.1 Search terms and strategy

The following electronic databases were selected and searched to conduct this systematic review: ACM (Association for Computing Machinery), IEEE (Institute of Electrical and Electronics Engineers), Google Scholar, and Scopus. The following search terms were used: "computational thinking" and "English", "computational thinking" and "English language", "computational thinking" and "English language curriculum", "computational thinking" and "English language course", "computational thinking" and "English teaching" and "English learning". In pilot searches,

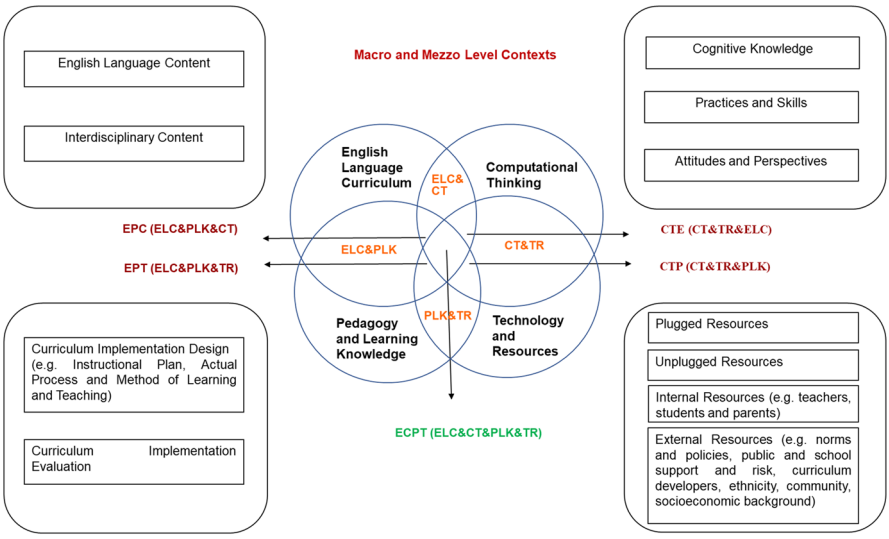

Fig. 1 The conceptual framework for literatures analysis

search engines for different databases appeared to use different syntaxes for search strings. Therefore, this study appropriately adjusts the search terms to suit different databases.

3.2 Study selection

3.2.1 Eligibility criteria

To select studies, a protocol based on the recommendations of the PRISMA statement was used (Page et al., 2021). The study selection process occurs in phases represented in a flow diagram (see Fig. 2). The following inclusion and exclusion criteria were implemented to determine which studies could be included in this review.

- Inclusion criteria 1: Full articles published in journals and conferences with peer review.

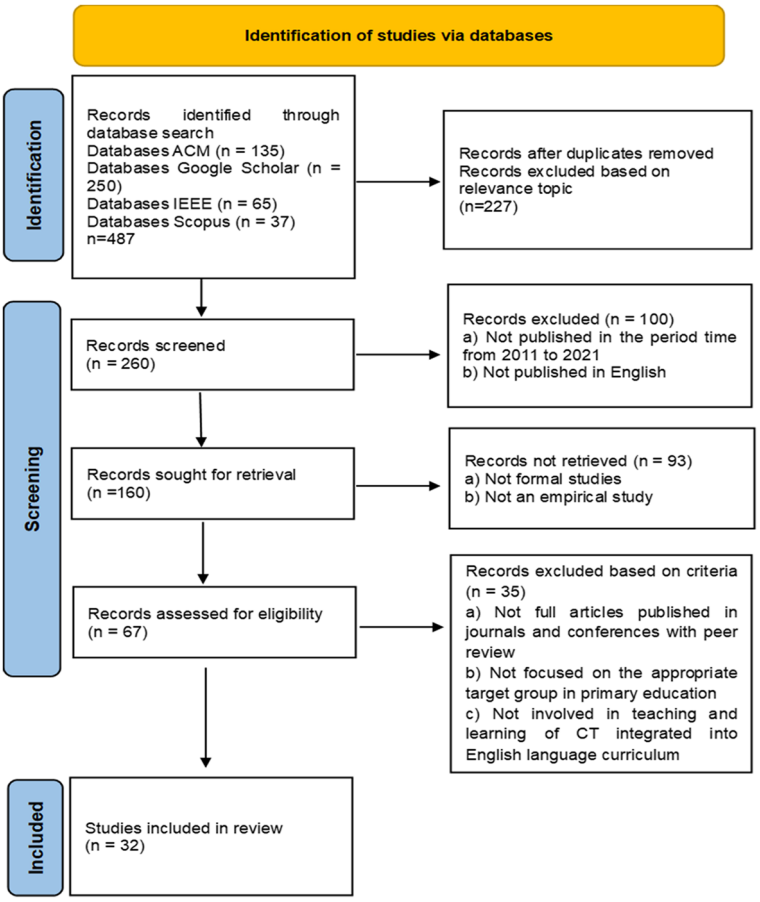

Fig. 2 Overview of the search protocol based on the PRISMA statement

- Inclusion criteria 2: Articles reported studies conducted in primary education.
- Inclusion criteria 3: Studies involved in teaching and learning of CT integrated into the English language curriculum.

The following exclusion criteria were implemented to determine which papers could not be included in this review.

- Exclusion criteria 1: Study publications outside the period time from 2011 to 2021 were excluded.
- Exclusion criteria 2: Studies not written in English were excluded.
- Exclusion criteria 3: Studies without abstracts or other papers' forms (such as posters, presentations, idea papers, etc.) were excluded.
- Exclusion criteria 4: Studies not belonging to the empirical study were excluded.

This study obtained criteria research results by identifying application search terms and strategies. Inclusion and exclusion criteria should apply to each searched study and should be validated by a panel of university professionals. Firstly, 487 articles were collected. The 32 articles were finally reviewed for further reading and quality criteria to ensure that the selected papers met the inclusion and exclusion criteria and that the selected works were of a quality to answer research questions.

3.2.2 Quality criteria

Quality criteria are presented in the form of questions with coded elements. It was validated by a panel of university professionals, who assessed each item for clarity, relevance, and suggested revisions. Several criteria were employed to ensure the quality of the included studies. Firstly, the search was performed in databases known for CT and English language curriculum in primary education. Secondly, the journals and conferences that published the studies had to require peer review. Thirdly, the authors of this article reviewed the methodology and the process of the selected studies. Based on consensus, those studies missing important descriptions of methodology and process were excluded.

3.3 Coding

In total, 32 papers related to CT in the English curriculum were analyzed and coded to provide aggregated data results. Different topics were examined in each selected paper to answer research questions. Firstly, the coding scheme was developed based on the theoretical analysis of CT-TPACK and selected studies, which includes CT (cognitive knowledge, practices and skills, attitudes and perspectives), English language curriculum (English language content), pedagogical and learning knowledge (curriculum implementation design, curriculum implementation evaluation), technology and resources (plugged resources). Secondly, using the original coding scheme, the author reviewed and coded a random selection of 10 papers. During the review process, we checked and improved the initial coding scheme by revising and

clarifying categories. Specifically, we have added elements that include the English language curriculum (interdisciplinary content), technology and resources (internal resources, external resources, unplugged resources) to enrich the theoretical framework and literature analysis. Thirdly, after the coding scheme was stabilized, we discussed and modified issues that arose during the coding process. In the last stage, the first author independently coded the remaining publications when an acceptable agreement with the coding scheme had been reached.

The following details each dimension of the coding system:

- Nationalities, authors, and publication year: The basic information on published papers is discussed to understand research trends.
- Levels of education: It refers to the grade and age of the participants.
- Research methodology: It relates to the type of methodology—qualitative, quantitative, or mixed method—that is employed in the selected studies.
- Content knowledge (English Language Curriculum): It refers to code through English language content and interdisciplinary content in selected studies.
- Content knowledge (Computational Thinking): It primarily refers to the CT, which is coded explicitly through cognitive knowledge, practices and skills, attitude and perspectives.
- Pedagogy and learning knowledge: It relates to how content knowledge is taught by teachers to students while they learn CT and subject knowledge. It is coded through curricular implementation processes, techniques, and evaluation.
- Technology and resources: It refers to the technology and related resources emerging in selected studies which focuses on internal, external, plugged, and unplugged resources for curriculum teaching and learning.
- Integration results and relationships: It focuses on impacts of CT integrated into the English language curriculum. The results identify changes of curriculum integration in content knowledge, pedagogy and learning knowledge, technology and resources.

3.4 Data management, analysis, and extraction

Results of the database search were imported into the reference management software program Mendeley. The Mendeley repository includes all manual citations for the results of the chosen literature searches, after which data was imported into NVIVO 12. Duplicates were removed and all steps of the process were recorded in MS Excel files to ensure replicability and transparency of the search process. This review identified CT incorporated into English language curriculum teaching and learning in primary education. Elo and Kyngäs' (2008) inductive content analysis method guided the selection of studies with steps, including selecting units of analysis, understanding data, open coding, coding tables, grouping, categorization, abstraction, and concept mapping. Two coders conducted a preliminary analysis of 10 papers and used the common dimensions of CT, English language curriculum, pedagogy and learning knowledge, technology and resources listed in the conceptual framework. Open coding allows for the collection, analysis, and classification of

additional information. The data extraction followed the coding scheme and is presented in the results section. In Table 1 in Appendix, articles are briefly described.

4 Results

4.1 Descriptive information about CT integrated into the English language curriculum

The selected articles have been developed in different countries on four continents: Asia, America, Europe, and Australia. Most of the selected studies originate from the United States ($n=17$), and Asia ($n=7$) including China (Taiwan) ($n=3$), China (Hong Kong) ($n=2$), Malaysia ($n=1$), and Japan ($n=1$). Other studies originate from European countries ($n=4$), including Italy ($n=1$), Spain ($n=1$), Austria ($n=1$), and Portugal ($n=1$). Canada ($n=2$), Australia ($n=1$), and Chile ($n=1$) are also considered in selected literatures. Non-native English speakers are increasingly recognizing the role of CT in learning and teaching within the English curriculum. Most of the articles come from native English-speaking countries such as the United States, Canada, and Australia probably because CT was focused earlier, and there are sufficient language contexts and conditions to apply it in curriculum reform. Although not linearly, the number of publications increased substantially between 2011 and 2021. The number of CT papers in 2021 is eight times more than in 2011. Figure 3 shows the publication situation of CT integrated into English language curriculum in primary education from 2011 to 2021. The analysis revealed that most of the studies ($n=20$) were focused on the primary education level. A small number of studies were also mentioned in various educational levels including primary and secondary education ($n=4$), primary and kindergarten education ($n=3$), and kindergarten, primary and secondary education ($n=5$). Among the selected articles, the research analysis methods include qualitative ($n=15$), quantitative ($n=9$), and mixed methods ($n=8$). This shows that qualitative methods have been conducted more than quantitative and mixed methods. Data collection and analysis for

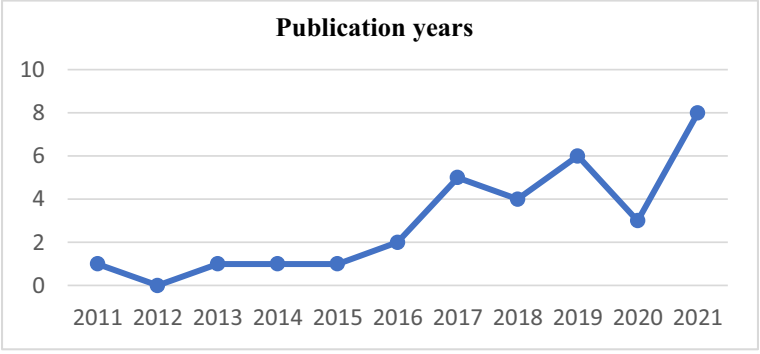

Fig. 3 The annual distribution of articles

quantitative research typically involved questionnaires, while qualitative studies utilized interviews. For mixed methods, the study with the qualitative analysis method includes interviews with teachers, professional development providers, and school administrators to understand how schools integrated CT into their specific settings. Additionally, findings were also obtained through structured quantitative classroom observations, as well as surveys of teachers or students.

4.2 What are components of CT integrated into the English language curriculum in primary education?

4.2.1 Components of CT for curriculum integration

The CT definition can be applied to solve problems with and without computers, and there are opportunities to integrate CT into the English curriculum (Jacob et al., 2018; Sherwood et al., 2021). CT in terms of cognitive knowledge can be integrated with the English language curriculum in primary education. The CT concepts that received the most attention are abstraction (using abstraction to create models of artificial or natural phenomena and simplifying complexity to define a main idea), algorithms (solving problems by following a detailed set of instructions or steps), and data collection, analysis, and representation (obtaining, assessing, and representing data using words, graphics, or models) (Barr & Stephenson, 2011; Dong et al., 2019). Many authors also focused on the role of problem formulation (Yadav et al., 2014), problem decomposition (breaking down complicated problems into manageable and smaller parts to easily solve), pattern recognition and sequence (Saito-Stehberger et al., 2021) for curriculum integration. Meanwhile, loop (Jenkins, 2015), logical thinking (Weng et al., 2018), and creativity (Pektas & Sullivan, 2021) have been mentioned frequently. Other studies have focused on automation (automating solutions with digital tools) (Barr & Stephenson, 2011), conditionals (Hsu & Liang, 2021) and parallelism (arranging resources and making things happen simultaneously to complete activities that contribute to a similar purpose) (Mouza et al., 2017). A few articles focus on critical thinking (Yadav et al., 2014), evaluation (Zaman et al., 2019), simulation (a representation of a process) (Mouza et al., 2017), operators (Smith & Burrow, 2016), and iteration (Nesiba et al., 2015).

The data indicates significant opportunities for integrating CT practices and skills with the English language curriculum in primary school. CT is seen as a problem-solving approach or process and can be applied to interdisciplinary content in the English language curriculum (Jacob et al., 2018). Specifically, the operationalized problem-solving process includes the practice of CT concepts with techniques and strategies for problem formulation, problem generalization, data organization, data analysis, data representation, solution identification, solution analysis, and solution implementation (CSTA & ISTE, 2011). Modeling is frequently mentioned as one of the practical strategies of CT. Sabitzer et al. (2018) emphasized the modeling process as a highly structured method of solving problems, which designs an image or diagram (model) of reality at a highly abstract level, such as structure, attributes, relations, activities, processes or behavior. A study presented five CT practices

such as algorithms, debugging, abstraction, decomposition, and patterns through unplugged activities, and illustrated examples of how these CT practices could be integrated into various primary school subject areas (Moudgalya et al., 2021). Students learn CT through algorithmic processes, providing essential scaffolding for successful problem solving (Jacob et al., 2020). In addition, the CT approach involves tinkering with the design elements of the system, collaboratively creating tests, and modifying programs (Pektas & Sullivan, 2021). CT processes including debugging and revising (Saito-Stehberger et al., 2021), remixing and experimenting (Vogel et al., 2019) were considered in the selected studies. Specifically, the research effectively integrated computational practices (experimenting & iterating, testing & debugging, reusing & remixing, abstracting & modularizing) into corresponding language arts standards (writing routinely over extended time frames; planning, revising, editing; recalling and gathering information; using linking words to connect ideas within categories) (Smith & Burrow, 2016).

CT in terms of attitudes and perspectives can be integrated with English language curriculum content in primary education. Most studies emphasize the important role of expression and collaboration in curriculum integration (Pektas & Sullivan, 2021; Weng et al., 2018). CT perspectives are frequently utilized as "connecting", "questioning", and "expressing" (Mueller et al., 2017) and have been integrated into language arts standards (Smith & Burrow, 2016). Debugging and troubleshooting require persistence, comfort with ambiguity, and a positive view of making mistakes (Jacob et al., 2018). There is a study focused on integrating CT into core content area activities to improve attitudes or perspectives, such as perseverance and general cooperation so that students feel confident using English vocabulary (Sherwood et al., 2021).

4.2.2 Components of English language content for curriculum integration

Numerous studies have explored the potential integration of CT with English language curriculum content in primary education in terms of knowledge and skills, processes and procedures, perspectives and attitudes, and cultural awareness. Knowledge and skills mainly focus on reading and writing, followed by speaking and listening. As for writing skills, this includes studies on fiction writing (Pektas & Sullivan, 2021), writing digital stories (Parsazadeh et al., 2021), writing outlines and identifying arguments (Dong et al., 2019), writing instructions and stories with branches (Sabitzer et al., 2018), and topic writing (Federici et al., 2019). For instance, Smith and Burrow (2016) found that writing skills ("use temporal words to signal event order; planning, revising, editing; develop experiences, events, and characters; organize event sequence that unfolds naturally; planning, revising, editing; produce writing developed and organized to appropriate task and purpose; recall and gather information") correspond to computational concepts (sequence, loops, parallelism, events, conditionals, operators, data). Moreover, Mensing et al. (2013) emphasized the ability to construct logical arguments based on substantive claims, sound reasoning, and pertinent evidence. CT concepts can be embodied through English content, such as abstraction (write a story with branches) and algorithm (write instructions) (Barr& Stephenson, 2011). CT can provide a systematic

approach to enhancing sentence structure and writing. Regarding reading skills, several studies focus on reading stories (Parsazadeh et al., 2021), narrative and expository texts (Dong et al., 2019), text comprehension (Sabitzer et al., 2018), inferring characters' emotions from text-based evidence portraying (Vogel et al., 2019). Additionally, several studies have confirmed the CT integration effectiveness of English language speaking and listening skills, including oral presentations and explanations (Federici et al., 2019). The development of oral skills engages students by enabling them to share their ideas, provide feedback on peers' dialogue, and foster collaborative engagement (Costa & Pessoa, 2016). Language knowledge is a crucial foundation for developing language skills. Several studies suggest that English language knowledge such as phonetics, vocabulary, grammar, discourse, and pragmatics should be integrated with CT. Specifically, it focuses on English phonetics (vowels and consonants), lexical categories (verbs, nouns and articles) (Simmonds et al., 2019), and English phrases (Federici et al., 2019). As for vocabulary, vocabulary application (Hsu & Liang, 2021), word spelling (countable and uncountable; plural and singular) (Federici et al., 2019) and numerical expression (Smith & Burrow, 2016) are considered in studies. Sentence grammar is addressed through correct construction of sentences (Simmonds et al., 2019), linguistic analysis to identify and represent patterns of different sentence structures and types (Yadav et al., 2014), writing out standard English sentence structures (Vogel et al., 2019), and breaking sentences into different parts or grammatical units, such as subjects, verbs, and objects (Weng et al., 2018). Other English language knowledge is organized through simile and metaphor (Sabitzer et al., 2018), idiom literacy exercise (Mensing et al., 2013), English dialogue (Weng et al., 2018), English alphabet (Domenach et al., 2021), storyline formation (Parsazadeh et al., 2021), story creation (Falkner et al., 2018), topics and story analysis (Strachman et al., 2020).

Numerous studies demonstrate how the English language curriculum involves CT in processes and methods to support learning and teaching in primary schools. Cognitive logic strategies can be used to correct sequences in confusing story combinations (Parsazadeh et al., 2021). Sequencing facilitates writing tasks, such as organizing paragraphs into topic sentences and main points, correctly ordering events in a story, or writing instructions for specific tasks. Entity-relationship, class or activity diagrams are highlighted in the integration of languages and CT into real-life topics for helping modeling stories, vocabulary classification, summarizing texts, oral presentations, visualizing grammar rules and logical steps of describing actions (Sabitzer et al., 2018). Besides, diagramming sentences via syntax tree can be used for native/foreign languages (Mannila et al., 2014). Communication and collaboration strategies are used to complete the integration activities of English language curriculum content and CT. Strachman et al. (2020) showed that active collaboration completes form-filling tasks for story structure. Students are willing to seek help from others when faced with problems about English dialogue and communication (Weng et al., 2018). Students could learn about the sequential process in CT and practice their English vocabulary and sentences through English game interactions (Hsu & Liang, 2021).

From perspectives and attitudes, the selected studies focused on students' confidence, collaboration, and perseverance to contribute with teachers and peers;

students' enthusiasm and interest in doing things; students' risk-taking to gain competence in new areas; students' confidence in their ability to be computational thinkers and complete computational tasks; and teachers' confidence and initiative to integrate CT skills into everyday instruction in the classroom. English writing perspectives and attitudes develop experiences, events, and characters; use technology to publish writing, interact and collaborate with others; conduct short research projects that build knowledge with computational perspectives (expressing, connecting, questioning) correspondingly (Smith & Burrow, 2016). From cultural awareness perspectives, some studies use foreign literary works to show cultural knowledge and comprehension. English texts allowed low socioeconomic status, multilingual, and marginalized groups to use their multimodal and multilingual skills to create literature that reflected their personal and social identities. Students can insert their voices as active participants in the dominant culture, promoting the use of creative media design (Jacob et al., 2018).

Interdisciplinary lessons with CT allow students to apply knowledge from different areas for problem solving. English language learners in STEM thematic topics are well-proven (Jacob et al., 2018). The Collaborative Computational Thinking Design Practices (CCTDP) framework offers valuable assistance in addressing open-ended STEM-related problems within English education (Zaman et al., 2019). Interdisciplinary knowledge can influence English content, for example by understanding history to inspire fiction, demonstrating effective use of concepts and establishing the parallel relationship between history and stories. Social studies are also mentioned as an interdisciplinary component of the English curriculum content (Strachman et al., 2020). CT can facilitate bilingual learning and other languages such as Spanish (Vogel et al., 2019). Moreover, interdisciplinary digital storytelling and English writing help students solve problems about abstract parts of story plots, and expand their English language and CT knowledge (Pektas & Sullivan, 2021).

Teaching English as a native language in some countries mainly emphasizes English writing and reading. However, English as a second or foreign language in some countries mainly focuses on English grammar, vocabulary, sentences, reading, conversation, and storytelling (Weng & Wong, 2017; Weng et al., 2018). They are both concerned with learning and teaching interdisciplinary knowledge through English content. This may be strongly influenced by the language context, students' language development needs, education system, curriculum objectives, and other requirements of the country in which English is taught and learned.

4.3 How have implementations of CT integrated into the English language curriculum been designed in primary education?

4.3.1 Pedagogy and learning knowledge for CT integrated into the English language curriculum

Teachers attempt to address possible teaching opportunities for integrating CT with English language content. Previous research has established that the main teaching organization ways include integrating CT into existing whole-school collaborative

learning activities, practices and curriculum standards embedded into existing curricula, and CT integrated into regular classroom teaching in key grade levels (Sherwood et al., 2021). Researchers have begun to design pedagogical frameworks for facilitating CT implementation in the English language curriculum. The case study was used to demonstrate how teachers have successfully identified CT and infused it into their subject domains by using the PRADA (Pattern Recognition, Abstraction, Decomposition, Algorithms) model (Dong et al., 2019). Following the CCTDP (Collaborative Computational Thinking Design Practices) paradigm, Zaman et al. (2019) employed a qualitative ethnographic approach to illustrate the literacy and cognitive flow of primary school teachers and students during an interactive CT activity. The CDIO (Conceive-Design-Implement-Operate) as a teaching framework can help students think and solve problems in English lessons (Hladik et al., 2017).

Pedagogical approaches are crucial in curriculum implementation. Sherwood et al. (2021) found three integration approaches, including the single teacher-leader-driven model, the scaffolded professional development model, and the intensive coaching model. Besides, linguistic scaffolding and culturally responsive pedagogies effectively support CT instruction. As for linguistic scaffolding, the vocabulary, syntax, and features used to describe CT in academic language differ from everyday language (Jacob et al., 2018, 2020). Culturally relevant teaching not only validates students' identities beyond content knowledge teaching but also cultivates students' CT skills while fostering creative thinking and social negotiation (Jacob et al., 2018). Teaching strategies also included interdisciplinary teaching practices, group work, cognitively demanding work, and students' intellectual risk-taking (Century et al., 2020). One of the key challenges faced by teachers is the appropriate selection of instructional strategies to support English language learners in acquiring CT concepts. Previous studies have examined pedagogical strategies integrated with CT instruction, including unplugged activities, technology utilization, computational tools, CT academic language, and project-based learning activities (Sherwood et al., 2021). Additionally, teachers have employed methods such as creating interactive animations to explain topics, designing game-like projects (Simmonds et al., 2019), developing instructional software (Strachman et al., 2020), and implementing translanguaging pedagogy (Vogel et al., 2019). Furthermore, teachers guided students through modeling, supervising, answering questions, recalling knowledge, and integrating knowledge to solve problems. Specifically, primary teachers can develop games and use modeling to visualize game rules, aiming to increase motivation through a creative and interdisciplinary approach to English as a foreign language learning (Sabitzer et al., 2018). In language teaching, instructors use the 'present, practice, produce' approach to innovative present CT in English storytelling (Parsazadeh et al., 2021).

Curriculum learning should consider students' cognitive abilities and learning experiences to achieve both CT and English education. Creating a supportive classroom atmosphere is essential for teachers to foster student engagement and alleviate language learning anxiety. Teachers facilitate discussions on ways to improve students' creativity and problem-solving (Weng & Wong, 2017). Furthermore, students use different learning methods and tools, for instance, flowcharts help students analyze and solve problems, making it easier to logically organize the English

language and correct mistakes in time (Sabitzer et al., 2018). The multimodal interaction approach proposed by Zaman et al. (2019) demonstrates that students inherently have a problem-solving orientation and can be nurtured through CT concepts. The collaborative inquiry-based learning process is proposed as an ideal for learning computer science content and language (Smith & Burrow, 2016) with open approaches to inquiry (independence during investigations with teachers' guidance and peers' collaboration) and structured approaches to inquiry (problem formulation methods and demonstrating computational principles) (Jacob et al., 2020). Constructivist learning methods are conducted to build a "5E's" (Engage, Explore, Explain, Elaborate, and Evaluate) model to facilitate inquiry-based teaching and enhance students' learning (Jacob et al., 2020). Several studies have demonstrated the strategic effectiveness of both unplugged (i.e., non-computer-based) and plugged (i.e., computer-based) activities with computational tools on collaborative project-based learning (Sherwood et al., 2021). Plugged activities might be organized for vocabulary, grammar learning (Moreno-León & Robles, 2015), and story writing (Pektas & Sullivan, 2021). In a study that aimed to simultaneously enhance students' interdisciplinary performance in English and CT through unplugged and plugged approaches, Hsu and Liang (2021) reported that the plugged approach effectively reinforces CT and English language while reducing language learning anxiety and promoting critical thinking; the unplugged approach facilitates CT and English language practice, fostering a cooperation tendency among students.

4.3.2 Technology and resources for CT integrated into the English language curriculum

Technology and resources are considered to support student learning and teacher teaching. The integration of CT into the English language curriculum enables students to find solutions to everyday problems with technology and resources (Jacob et al., 2018). Integrating structures and resources can help teachers think about subjects they currently teach and which subjects they can and should integrate CT with lesson plans (Garvin et al., 2019). Primary teachers have identified various helpful resources for teaching, including graphic organizers, templates, slide presentations, and coding guides (Dong et al., 2019). Resources can create and showcase artifacts to improve students' learning motivation and engagement (Liu et al., 2017). Technology and resources need to be set up in a way to meet the students' ability levels (Strachman et al., 2020). Previous studies have demonstrated the accessibility and convenience of plugged tools in both CT and English language curriculum activities, even for foreign language teachers without computer programming experience (Federici et al., 2019). Technological resources have been widely discussed by researchers to assist curriculum integration, such as videos, pictures, animations (Wolz et al., 2011), PowerPoint (Parsazadeh et al., 2021), the ToonDoo tool, online comic-creation tools (Tatar & Eseryel, 2019), online lesson plans (Saito-Stehberger et al., 2021), e-books, multimedia and online platforms (Liu et al., 2017), web applications (Weng et al., 2018), concept-mapping software. In addition, Google (documents, sites and bloggers) (Nesiba et al., 2015), Internets, interactive whiteboards (Grover & Pea, 2013), robots (Hsu & Liang, 2021), laptops (Burke & Kafai, 2012),

iPads (Liu et al., 2017) are also considered. Digital tools have been used as visual block-based programming environments for microworld activities to support CT and English learning and teaching, including Scratch (Costa & Pessoa, 2016; Pektas & Sullivan, 2021), Snap! (Jenkins, 2015), BlockLang (Federici et al., 2019), Alice (Jacob & Warschauer, 2018), Kodu (Weng & Wong, 2017), Logo Turtle (Burke & Kafai, 2012), StoryMode (Strachman et al., 2020), MIT App Inventor and Game Maker (Tatar & Eseryel, 2019). Additionally, Codecademy (Mensing et al., 2013) and LOGO as text-based programming languages are also considered in activities (Jenkins, 2015). Unplugged activities can be implemented with unplugged tools such as Paper (worksheet), Pen/Pencil (Parsazadeh et al., 2021), vocabulary cards (Jacob et al., 2018), colored student workbooks (Saito-Stehberger et al., 2021), and textbooks (Domenach et al., 2021). These unplugged activities emphasized teaching and learning CT without the need for computers, which involve puzzles, cards, string, and crayons (Bell et al., 2009).

CT integrated into the English language curriculum is supported by external resources. These resources include local teacher leaders, multidisciplinary collaboration between university and secondary school teachers, national policymakers, training for relevant staff assistance, supervisor or central office staff, media center specialists and technical teachers, family and friends, CT expertise, and the nonprofit organization Code.org. Furthermore, school leaders, school administrators, computer science researchers at the university, and local business leaders also contribute to this area. The selected studies highlight the role of CT in non-CS disciplines and how CT fits with current standards and works through organizational formats such as conferences, workshops, learning communities, summer institutes, and peer collaborative learning provided by teachers with CT experience. Professional development providers and training may introduce CT by showing how teachers can use CT knowledge and practices in the teaching content (Houchins et al., 2021; Moudgalya et al., 2021). However, common barriers are low internet speeds, computer problems and limitations in accessing specific websites within the school environment (Falkner et al., 2018). As for internal resources, Simmonds et al. (2019) found that teachers were initially nervous about curriculum integration in the field of CT, however, they gained confidence in using CT and Scratch to design new teaching programs after implementation. Students' attitudes toward language and their surroundings influence their language transfer and peer editing (Vogel et al., 2019). Additionally, personal challenges are identified such as time constraints due to personal reasons, workload, work pressures, and life events that may limit teachers' participation or modules' completion (Falkner et al., 2018).

4.4 How to evaluate teaching and learning of CT integrated into the English language curriculum in primary education?

Evaluation of curriculum implementation benefits both students and teachers. Previous research has identified four instructional evaluation criteria for lesson plans, including (a) curriculum objectives and techniques: technologies and practices to support CT knowledge and skill development; (b) instructional strategies and

techniques: emphasizing the use of technologies to promote CT knowledge and skills among students; (c) technology choice: compatibility with curriculum objectives and teaching strategies; and (d) adaptation: consistency in content, pedagogy, and technology to promote CT knowledge and skills (Mouza et al., 2017). Classroom assessments are conducted through an observation protocol, encompassing lesson objectives, classroom management practices, strategies to enhance student motivation, teaching strategies, questioning levels, teacher and student interactions, teaching materials/tools used, and evaluation (Weng & Wong, 2017). The bidirectional transfer between teacher assessment and student self-assessment is crucial for CT to optimize assessment (Mueller et al., 2017). The selected articles have evaluated curriculum implementation effects by assessing content, activities, and tools. Costa et al. (2016) focused on the progress assessment of students' English skills (listening, reading, writing, speaking, and intercultural domain). The effect of CT methods on students' storytelling ability was assessed by a rating scale in the control and experimental groups before and after the test (Parsazadeh et al., 2021). Various approaches, including plugged and unplugged methods, game-based activities, and interactive approaches, were evaluated for their impact on overall English learning performance, student anxiety, interdisciplinary learning, and CT learning (Hsu & Liang, 2021). Participants' anxiety levels were assessed using the Foreign Language Classroom Anxiety Scale (FLCAS) (Horwitz, 1986) in an integration experiment. The Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich et al., 1993) evaluated the effectiveness of integrating CT and digital storytelling in improving students' learning motivation. Observational assessments are used to understand the effectiveness of learners' cognitive processes and analyze their interactive strategies for acquiring, building, maintaining, and developing knowledge within peer groups. The observational assessment examined how students learned from previous experience and knowledge; how visual presentation and socialization made adjustments to change what they knew; and how they organized thought and action related to the 'logic-decomposition-abstraction' (LDA) orientation of problem-solving (Zaman et al., 2019). Studies also evaluated the characteristics and effectiveness of tools in activities, confirming whether tools perform well in tasks and alignment between human and automated assessments in Scratch projects (Moreno-León & Robles, 2015; Simmonds et al., 2019). Automated assessments through Dr. Scratch measure CT development in Scratch projects, including logic, data representation, user interactivity, flow control, abstraction, parallelism, and synchronization (Weng & Wong, 2017).

The study findings highlight the significance of using diverse assessment approaches for curriculum implementation. Teaching and learning evaluations have been conducted through formative and summative assessments with quantitative and qualitative methods. Teachers play a crucial role in curriculum development, contributing through improvement suggestions, observation, and student feedback (Saito-Stehberger et al., 2021). Student assessments during curriculum implementation include informal formative assessments for monitoring progress and formal summative assessments based on specific criteria. Linguistic frameworks are useful for formative assessment, enabling teachers to monitor emerging literacy skills during students' individual reflections and group discussions (Jacob et al., 2018).

Programming artifacts can help students' understanding about cognitive knowledge of CT, practices and skills of CT (Parsazadeh et al., 2021). Students are evaluated through pre- and post-assessments, English proficiency tests, CT tests, and questionnaire surveys for cooperation, critical thinking, and foreign language learning anxiety (Hsu & Liang, 2021). Assessment tests can combine closed-ended and open-ended questions (Federici et al., 2019). Additionally, students' interviews were also used to comprehend how programming tools can assist CT with English language learning (Weng et al., 2018). Self- and peer-assessment support students' self-reflection and their peers' progress in courses (Saito-Stehberger et al., 2021). Teachers' verbal protocols provide insight into students' CT skills and their relation to problem-solving (Mueller et al., 2017). Regarding teachers' teaching, most of the studies focus on teachers' feedback, reflections, and interviews that have led to curriculum revision and pedagogy for integrating CT into the curriculum (Weng &Wong, 2017; Sabitzer et al., 2018). Teachers' teaching evaluation uses various methods and instruments to test the effectiveness of CT integrated into the subject curriculum. This assessment may encompass teacher products (learning segment plans, block-based programming prototypes, and related artifacts), daily reflections, pre- and post- professional development surveys, feedback forms from teacher presentations, and audio recordings of teacher interviews (Dong et al., 2019). Some assessment surveys mentioned teachers' perceptions of CT concepts, resources, and integration in their classrooms (Garvin et al., 2019; Moudgalya et al., 2021). Teaching evaluations also explored interdisciplinary collaboration through surveys, handwritten notes, and project creation (Simmonds et al., 2019).

4.5 What are results and impacts about teaching and learning of CT integrated into the English language curriculum in primary education?

Most of the studies show that CT can enhance students' learning of English curriculum content. CT strategies can facilitate the learning of English as a second language (Parsazadeh et al., 2021). It has been suggested that students' language practice transfer in the context of CS learning can blur the boundaries of language, discipline, and modality (Vogel et al., 2019). CT can be taught seamlessly within an English literature course while maintaining expectations for course descriptions, teaching requirements, and student performance. This integration fosters positive engagement, enthusiasm, enjoyment, and confident attitude among students. CT strategies had a positive effect on students' problem-solving skills, grammar, reading, and writing skills, as well as improving their motivation and performance in English language learning. Computational literacies can be intertwined with many other competencies that students bring with them (Vogel et al., 2019). Jacob et al. (2020) reported that students who took more structured inquiry courses developed more complex computational artifacts and greater identification with the field of computer science.

Effective teaching is essential to guide student learning. Student collaboration on computing inspires problem solving and three main modes of collaboration, including teacher-prompted collaboration, organized collaboration, and student-initiated

collaboration are encouraged. The CCTDP framework plays a crucial role in facilitating the transition from rote thinking to CT, where learners can use certain directions to generate their ideas and construct new ways of solving problems (Zaman et al., 2019). This framework empowers students to become competent learners and teachers to develop their pedagogical strategies. Introducing CT into teacher education programs has proven effective in enhancing teachers' understanding of CT and their ability to integrate it into their future classrooms and content areas (Mouza et al., 2017). Teachers have a more positive, initiative, and confident attitude toward CT and curriculum integration after the course teaching. Teachers initially expressed concerns about teaching CT, but their worries lessened as they gained more experience. Specifically, teachers have a better understanding of CT beyond the use of computers and technology, and how to integrate CT into their future teaching by promoting algorithmic thinking, abstraction and problem solving (Yadav et al., 2014).

Both plugged and unplugged resources help students engage in active and effective learning activities. Students can be positive, creative, and confident with tools for effective learning, and learn to collaborate and communicate with others. Sabitzer et al. (2018) found that modeling is useful and feasible in unplugged learning environments. According to survey results, students are motivated and have positive perceptions of using visual programming languages for their English and problem-solving abilities (Pektas & Sullivan, 2021; Strachman et al., 2020). Students remained highly enthusiastic, motivated, and enjoyable with Scratch learning and interactions with teachers in intervention studies (Weng & Wong, 2017). They have responded very positively to coding and improved projects with peers' help (Costa & Pessoa, 2016). Furthermore, students have recognized the importance of learning English by themselves for information searching on the Internet (Moreno-León & Robles, 2015). Students showed lower error rates if the English topics were taught through interactive tools based on block programming metaphors (Federici et al., 2019). Additionally, a narrative-centered learning environment facilitates creative digital storytelling with custom narrative blocks and provides an engaging environment for students to study science, English language art and CT (Houchins et al., 2021).

In summary, CT integrated with the English curriculum in primary education can be influenced by a combination of CT content, English language content, pedagogy and learning knowledge, technology and resources in macro- and mezzo-level contexts, resulting in both positive and negative outcomes. This integration has distinct characteristics that present both challenges and opportunities (Jacob et al., 2018). The research highlighted that making time for computer science (CS) and computational thinking (CT) in primary school does not negatively impact time devoted to core subjects such as English language arts and mathematics (Century et al., 2020). The positive impact of curriculum implementation requires support for the teacher professional development training and the grades taught (Sherwood et al., 2021). Teachers ultimately take ownership of CT integration in a scaffolding manner by watching professional development providers demonstrate CT implementation. The CT model supports the core content that teachers need to successfully integrate CT into their existing curriculum and increases their self-efficacy in CT integration

designing and teaching (Dong et al., 2019). The CT integration strategy needs to leverage existing lesson preparation time and structure rather than requiring teachers to have additional time to plan (Sherwood et al., 2021). However, the negative impact of curriculum implementation stems from the fact that it is difficult to implement in schools with fewer computers, technology, staff, and content area expertise. There is confusion among teachers about the approach to integrating CT into subject teaching (Dong et al., 2019). Some teachers' superficial understanding of CT means they are unable to design courses that meaningfully integrate CT concepts and tools with subject content and pedagogy (Mouza et al., 2017). Some teachers are confused when they start using the block-based programming interface, suggesting the need for additional guidance and instructional support.

5 Discussion

The integration of CT with curriculum is a fast-growing field, and researchers have been exploring the integration of CT into English language curricula over the past decade. Through this systematic review, we described the current implementation of CT integrated with the English language curriculum in primary education. This study develops a conceptual model to identify the relationship and roles that CT can be integrated into the primary English curriculum with technology and resources for teaching and learning. The results show that CT, English language curriculum, pedagogy and learning knowledge, technology and resources as important components that together contribute to educational goals by playing different roles. The key findings are discussed below to solve research questions and explain future work in CT integrated with the English language curriculum. The limitations of this study are also discussed.

Firstly, most articles focus on CT integrated with English language curriculum in primary education in Western countries. The influence of society, economy, culture, politics, environment, and policies emphasize the role and value of CT in the English language curriculum, which improves students' adaptation to technology and the needs for future survival and development (Garvin et al., 2019). Educational goals are set for CT integrated into curriculums that drive student learning and teacher teaching (Pektas & Sullivan, 2021). From a disciplinary perspective, the specific content of the English language standards can be addressed through CT processes (Mensing et al., 2013). Research gaps need to be filled for large samples of over 200 people in formal and informal education contexts. Jacob et al. (2018) suggested that informal educational contexts such as informal language in students' everyday experiences, after-school activities, and workshop training play a key role in the implementation of CT integrated with English language education. Although researchers have tried to implement CT integrated with the English language curriculum appropriate for primary education, it is challenging due to limitations of students' and teachers' cognition in multicultural, socially, and economically vulnerable contexts. However, researchers have focused more on countries where CT integrates English as a native language curriculum than on countries where English as a second or foreign language. Therefore, it is necessary to

further enrich the literature on examining CT integrated with English as a second or foreign language in primary education. CT is a new indicator in the research to design English language curriculum activities and promote integration implementation in the classroom. By doing so, researchers and practitioners can find resources for a comprehensive developmental trajectory of CT integrated with the English language curriculum.

Secondly, the selected articles focus on theories related to cognition, language, pedagogy, and technology to achieve research aims. Most studies that have been conducted use a single theory such as constructivism theory, cognitive load theory, second language acquisition theory, TPACK framework, project-based theory, and active learning theory to analyze the issues that arise from the integration of CT into English language curriculum. However, it still lacks theoretical integration models to effectively support the development of research and curriculum practices for specific disciplines. Research methods primarily focus on the implementation of curriculum integration in the classroom through case study, quasi-experimental study, intervention study, design-based research, and action research. Other studies have investigated teachers' and students' CT skills with quizzes, attitudes with questionnaires, and the effectiveness of implementation with interviews or questionnaires. To sum up, qualitative research has been conducted more than quantitative and mixed research. It is vital that existing research experiences by using different research methods are enriched in different types of schools.

Thirdly, CT in terms of cognitive knowledge, practice and skills, attitudes and perspectives can be integrated into the English language curriculum in primary education. When CT takes a leading role and serves as the implementation goal in curriculum integration, English language curriculum content can be used as a subject context to complete CT or/and English language subject learning and teaching tasks (Barr & Stephenson, 2011). In addition, CT can be used as a supporting role and context in curriculum integration to help solve English language problems and increase subject knowledge understanding through thinking skills, problem solving processes, attitudes and perspectives for learning and teaching (Hladik et al., 2017; Sabitzer et al., 2018). The selected studies highlight the CT role of collaboration, expression, connecting, and questioning in the English language curriculum. However, there is still less attention to curriculum integration in terms of attitudes and perspectives of CT.

Fourthly, English language curriculum content in terms of knowledge and skills, processes and methods, attitudes and perspectives can be integrated with CT in primary education to effectively implement teaching and learning processes in classroom activities. English language content can provide a platform for CT development, providing disciplinary support to further clarify and broaden the meaning of CT. However, more of the selected articles focus on reading and writing skills in the English language, and there is a need to enhance the exploration of listening and speaking skills in curriculum integration. Furthermore, interdisciplinary content in the English language curriculum can better help integrate CT into the curriculum and solve problems (Jacob et al., 2018). In terms of processes and methods, it mainly includes cognitive methods (Sabitzer et al., 2018), linguistic methods (Smith & Burrow, 2016), communicative methods, and digital resource methods in the

literature. Perspectives and attitudes emphasize motivational interest, confident will, cooperative spirit, and cultural awareness in English language learning (Parsazadeh et al., 2021). Further research is needed in the areas of processes, methods, and strategies, as well as cultural awareness perspective in CT integrated into the English language curriculum.

Fifthly, more research has emphasized the role of teachers integrating CT into the English language curriculum. There is a need for professional development and training for teachers to consciously integrate CT into their teaching practice (Houchins et al., 2021). At the classroom level, it still lacks research guiding teachers on effectively incorporating CT to meet existing English curriculum needs and organize teaching and learning activities. The teacher's role in the classroom also influences the choice of teaching strategies (Sherwood et al., 2021). In terms of teaching tools, there is more experimentation with digital teaching tools for activities, however, unplugged activities and tools need to be developed and designed. In addition, teaching content, cross-curricular content, games, and the teaching atmosphere can be used to improve the effectiveness of CT integrated into English language courses. The selected articles show that the constructivist approach is more engaging for students' learning. Students are mostly engaged in learning activities through inquiry-based learning methods (Jacob et al., 2020), problem-based collaborative learning (Zaman et al., 2019), plugged and unplugged learning (Hsu & Liang, 2021). However, challenges persist in developing effective assessment tools, methods, and frameworks that align with both student and teacher requirements in the context of CT and curriculum integration.

Sixthly, technology and resources support the integration of CT into teaching and learning in the primary English curriculum influenced by external and internal resources, plugged and unplugged resources. Digital tools, particularly visual programming tools, interactive and presentational digital environments, are frequently utilized for their capacity to motivate, interest, and engage both teachers and students. In addition, unplugged activities and tools need to be developed to enhance CT and English language skills. Education administration, policies, and teacher training can help teachers and students improve their English and computer programming skills (Domenach et al., 2021). External activities and collaboration among staff facilitate the integration of CT into the English language curriculum (Barr & Stephenson, 2011). The future requires the development of related policies, integration of external and internal resources, reflection of CT and English language subjects. Further in-depth investigation of teachers' and students' abilities, needs, barriers with technology and resources are needed to facilitate the development of curriculum integration in the future.

Finally, CT as a direction for improving and facilitating English language teaching and learning needs to be considered. Most of the selected articles demonstrate positive outcomes for curriculum integration, with students and teachers benefiting from the use of technology and resources. Student-led inquiry and collaboration, guided by teachers emphasizing listening and sharing, show positive results (Costa & Pessoa, 2016). Teachers' attitudes towards CT and curriculum integration tend to become more positive, enthusiastic, proactive, and confident following the course implementation. Technology and resources can provide an engaging environment

that promotes interdisciplinary learning, English language arts and CT (Houchins et al., 2021). The role and the way of teachers in classrooms teaching need to be further explored. Teachers are supported by expertise that they are eager to incorporate into their teaching and collaborate with colleagues across disciplines during curriculum integration. Future training and guidance are essential to enhance teachers' experience, awareness, understanding, and use of CT to facilitate curriculum integration. Teachers need to be made aware of the interaction or coordination between subject content, CT, pedagogy and learning knowledge, technology and resources. However, negative effects of curriculum integration were also mentioned including teachers' superficial understanding of CT concepts, wrong choice of English curriculum content, inappropriate integration of subject and CT, poor student learning outcomes, and inadequate support for technology and resources in schools. Future research needs to be fully aware of the problems in the negative outcomes, explore implicit CT aspects in the English language curriculum, and understand the relationship between the various elements of curriculum integration. Continuous reflection on errors and learning from successful experiences is crucial for educators to design and implement effective curriculum integration.

The findings of this study should be interpreted in the context of limitations, and how these limitations can inform future research, providing suggestions for the application of CT integrated into English curriculums. The limitations and validity of this review are mainly in the following aspects:

Publication period and language. This study mainly collected articles from 2011–2021. Therefore, this study is limited to the time of articles' publication. Additionally, due to the language limitations of the researchers, this study only selected English articles for analysis.

Publication bias. Although few articles in this study had negative/neutral results, this overview may not provide a complete picture of developing CT integrated into English language curriculum teaching and learning in primary schools.

Articles selection and data extraction. This study was compared with previous systematic reviews for possible study inclusion. The study selection was limited to only four databases. It may not show all the work in the area.

6 Conclusion and recommendations

The English language curriculum, as the lock to be opened and the problem to be solved, needs a key like CT to unlock it. More importantly, CT needs to effectively match the English language content to solve problems. This study provides useful insight for policymakers, school administrators, curriculum designers, researchers, and teachers who are interested in integrating CT into primary education. Integrating CT with curriculum content in different educational contexts allows for specific goals and objectives to understand the value of curriculum integration. With a larger proportion of research related to programming, computer science, engineering technology, and natural science subjects, more researches are needed to examine how CT can be applied to a wider range of subjects such as the English language curriculum. The interplay between the components which includes the

definition of CT, English language curriculum, pedagogy and learning knowledge, technology and resources can enhance the effectiveness of curriculum integration and benefit each other. The relationship between them in this study can be progressively integrated from one element interacting with three elements, two elements interacting with two elements, and ultimately to an effective interactive integration of all four elements. The interaction process can be analyzed through both leading and supporting roles. In terms of pedagogy and learning knowledge, a specific discussion on their role, influence, and development in relational interaction is still missing and requires further enrichment through research.

The field of CT integrated into the English language curriculum is both fascinating and expansive. The findings demonstrated that excellent work had been done, but more remained to be done. In particular, we suggest that researchers and practitioners consider the following suggestions when designing CT integrated into English language curriculum: (a) create more CT integrated into English language curriculum for primary school in Asia, professional development, and informal education settings; (b) focus on the integration constructs aligned with the corresponding CT definitions and subject-matter knowledge in English to promote curriculum integration across various subject domains; (c) design and develop pedagogical practices in diverse school settings; (d) conduct surveys with large samples of teachers and students to understand their perceptions and attitude towards curriculum integration at the school and community levels in different countries; (e) understand the contexts, roles and interactions of CT, English language content, pedagogy and learning knowledge, technology and resources in curriculum integration; (f) develop effective theoretical interaction models and practical guidance frameworks for CT integrated with English language curriculum; (g) create more valid and reliable assessment tools to evaluate the effectiveness of curriculum integration; (h) develop CT and English language content for curriculum integration from knowledge and skills, practices and methods, attitudes and perspectives; and (i) provide training for professional development to empower teachers with confidence, motivation, and skills to integrate CT into the English language curriculum using appropriate pedagogical approaches and tools.

Finally, there is a need for further refinement and attention to the role, function, and relationship of curriculum integration. The development of various instructional designs and learning plans for different grade levels and disciplines in CT integrated into the English language curriculum suggests the creation of a searchable database to systematically collect, categorize, and organize these teaching cases. Such a database would enhance accessibility for researchers and practitioners with specific needs. The incorporation of specific learning objectives involving CT into the primary English language curriculum poses challenges for teachers with limited computer science knowledge. It presents both challenges and opportunities for integration of CT into the English curriculum across grade levels and interdisciplinary collaboration. Collaboration among teachers and researchers from different disciplines and education levels is essential for systematically designing and promoting the integration of CT with the English curriculum. This collaboration facilitates the transfer and progression of learning between grade levels and encourages students and teachers to apply CT skills to humanities subjects such as the English language subject.

Appendix

Table 1 Summary of the studies included in the systematic review

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Simmonds et al	2019	Chile	Kindergarten-Primary-Middle	qualitative method	CT: Practices and skills (creating) English language content: grammar, sentence	Project-based learning (PBL)	Scratch	• Systematic qualitative survey; • Dr. Scratch
Dong et al	2019	USA	Primary-Middle-High	mixed methods	CT: Cognitive knowledge (pattern recognition, abstraction, decomposition, and algorithms) English language content: reading of narrative and expository texts	PRADA (pattern recognition, abstraction, decomposition, and algorithms) themed infusing design	• Snap!; • Graphic organizers; • Templates; • Slides; • Coding guides assistance of computing experts	• Block-based programming prototypes; • Artifacts; • Pre- and post- surveys; • Daily reflections; • Feedback forms for teacher presentations; • Audio-recorded teacher interviews
Moudgalya et al	2021	USA	Kindergarten-Primary	quantitative method	CT: Cognitive knowledge (algorithm, abstraction); practices and skills (debugging) English language content: text structure and story	Integrating plugged or technology-based computing design	Scratch	Pre- and post- surveys
Vogel et al	2019	USA	Primary-Middle	qualitative method	CT: Cognitive knowledge (loops and conditionals); practices and skills (debugging and remixing); attitudes and perspectives (participating in computing to express, connect, question) English language content: bilingual in English and Spanish	Translanguaging pedagogy	• Scratch; • Programming environment; • Community	• Classroom observation (recorded field notes, audio of class discussions, photographs of students' screens, and student work samples)

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Sherwood et al	2021	USA	Primary	qualitative method	CT: Cognitive knowledge (decomposition, abstraction, algorithm, sequencing); practices and skills (problem solving, debugging, systematic thinking process, collaboration); attitudes and perspectives (perseverance) English language content: sequencing a story in the correct order	• Instructional strategies: single teacher leader-driven model, scaffolded professional development model, intensive coaching model • Ways of activities organization: existing school-wide collaborative learning activities, regular classroom instruction in grade levels, collaborative project-based learning activities	Unplugged and plugged (Scratch or robotics) computational tools	• Classroom observations; • Semi-structured interview with teachers; • Professional development for providers, and school administrators (teachers' reflection on their level of comfort in implementing and understanding of CT integrated activities within their curricula); • Cross-case analysis

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Barr & Stephenson	2011	USA	Kindergarten-Primary-Middle-High	qualitative method	CT: Cognitive knowledge: (data collection, data analysis, data representation, problem decomposition, abstraction, algorithms & procedures, automation, simulation) English language content: do linguistic analysis of sentences; identify patterns for different sentence types; represent patterns of different sentence types; write an outline; use of simile and metaphor; write a story with branches; write instructions; use a spell checker; do a re-enactment from a story	• N/A	spell checker	• N/A

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Garvin et al	2019	USA	Kindergarten-Primary-Middle	quantitative method	CT: Cognitive knowledge (decomposition, abstraction, patterns, algorithm, critical thinking); practices and skills (problem solving, using a computer or technology) English language content: daily lessons and across the core disciplines	Primary subject integration models	• Plugged resources: application or game, device, device with lessons, learning management software, programming software, and videos. • Unplugged resources: classroom materials. • Internal school resources: fellow teacher, technology teacher, IT support, school administrator, paraprofessional. • External school resources: websites, supervisor/central office personnel, community meet ups, media center specialist, local library, conferences/workshops, local nonprofit, professional development, family/friend, technology department, college professor.	• Survey was sent electronically via email to teachers for four survey constructs (CT concept, resources, integration, and comfort).

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Saito-Stehberger et al	2021	USA	Primary	qualitative method	CT: Cognitive knowledge (algorithm, sequence, event, loop, synchronization, debugging); practices and skills (problem solving process, pair programming plan, debugging) English language content: speaking and listening skills	Modification design; reflection and class discussion with interactive activities; scaffolded exercises using Use-Modify-Create and TIPP&SEE; pair programming activity; "Classmate Comments" activity	• Scratch; • Colored student workbook; • Online lesson plans; • Lesson slide decks; • Video; • Google forms	• Student and classroom observations; • Teacher feedback; • Specialist review of the curriculum; • Student learning assessment; • Bebras-type measurement; • Student interviews; • Online assessment tool with informal formative assessments as well as a self- and peer assessment; • Summative assessments
Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Jacob et al	2020	USA	Primary	mixed methods	CT: Cognitive knowledge (sequences, algorithmic processes); practices and skills (modeling, solving problems, simulating) English language content: literacy with STEM content	Inquiry-based curriculum with "5E" model (Engage, Explore, Explain, Elaborate, and Evaluate) with computer science and literacy standards; linguistic scaffolding; culturally responsive materials	Scratch	• Detailed field notes; • Teacher interviews; • Student computational artifacts; • Student identity surveys

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Falkner et al	2018	Australia	Kindergarten-Primary	mixed methods	CT: Cognitive knowledge (data, decomposition, abstraction, patterns, digital and information systems); practices and skills (problem solving strategies and techniques that assist in the design and use of algorithms and models) English language content: Sentence structuring; poem or song writing; procedure and narrative writing; story reading; story animation design and creation	Algorithm development activity: game exploring instructions and repetition, sequences of instructions, using flowcharts	• Popsticks; • Paper; • Pencil; • Blockly; • Scratch program; • Story book	• Topic content analysis; • survey

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Weng & Wong	2017	China (Hong Kong)	Primary	qualitative method	CT: Cognitive knowledge (sequences, loops, events, parallelism, conditionals, operators, data); practices and skills (being incremental and iterative, testing and debugging, reusing and remixing, abstracting and modularizing); perspectives (expressing, connecting, questioning) English language content: English dialogue learning, conversations, grammar	Constructionism design— "learning by making"	Scratch	• Class observation; • Programming projects (Scratch Artifacts); • Semi-structured interviews

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Moreno-León & Robles	2015	Spain	Primary	quantitative method	CT: Cognitive knowledge (abstraction and modularization; parallelism; synchronization; logical thinking; flow control; user interactivity; data representation) English language content: vocabulary, grammar, story reading, language explanation, writing, conversation	Programming learning and teaching design	Scratch	• Questionnaires; • Tests; • Surveys; • Source code analysis

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Sabitzer et al	2018	Austria	Primary-Middle	mixed methods	CT: Cognitive knowledge (decomposition, pattern recognition, pattern generalization, abstraction, algorithms, evaluation, data analysis, data collection, data representation); practices and skills (creating, modeling, debugging, collaborating, problem solving skills) English language content: oral presentations, text comprehension, story writing in the native or foreign language, vocabulary, visualizing grammar rules, creative interdisciplinary learning in English as foreign language	Modeling design; game design	Diagrams and flow charts	• Teacher observation; • Interviews and informal feedback from students and teacher

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Mensing et al	2013	USA	Primary	qualitative method	CT: Cognitive knowledge (iteration, abstraction, discretization, conditional parameters, logic); practices and skills (coding, debugging, collaborating) English language content: story writing with plot, semantics, context; syntax and grammar; text types; presentations, documents and blogging exercises on coding projects; animation and storytelling; listening and speaking; collaboration to international collaborations	Plugged activities design	• Scratch; • Blogs; • TelePresence and screen sharing	N/A

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Century et al	2020	USA	Primary	quantitative method	CT: Cognitive knowledge (algorithms, sequence, loops, and conditionals); practices and skills (debugging) English language content: English language texts	Literacy block design	Scratch	• Teachers' reflections (a post-implementation and post-attitude questionnaire); • Group reflection through the study's implementation survey instrument (teachers' self-report of their use of interdisciplinary teaching practices as well as their facilitation of group work, cognitively demanding work, and intellectual risk taking); • Student attitudes (questionnaires at pre- and post- intervention) toward school in general and toward CS; • Student academic achievement outcomes

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Domenach et al	2021	Japan	Primary	qualitative method	CT: Cognitive knowledge (logical thinking, creativity); practices and skills (problem-solving) English language content: communication skills	Unplugged activities and programming based activities	• Programmable educational robots; • Computer; • Online website; • Visual programming; • English language textbook; • Teachers; • Administrators; • Public school and university students; • In-service teacher training	• Pre-and post-workshops survey; • Observational notes; • Reflective research journal notes about the workshops

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Houchins et al	2021	USA	Primary	qualitative method	CT: Cognitive knowledge (creativity); practices and skills (problem-solving, debugging, tinkering, evaluation, collaboration) English language content: interdisciplinary learning; story creation, story dialogue and actions	Narrative-Centered Learning	Custom narrative-centered programming blocks	• Open-ended interview; • Record observations; • Qualitative thematic analysis

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Jacob et al	2018	USA	Primary-Middle-High	qualitative method	CT: Cognition knowledge (automation, abstraction, algorithmic thinking, modularization, and data analysis); practices and skills (problem-solving skills, debugging); attitude and perspective (persistence, comfort with ambiguity, and a positive view of making mistakes) English language content: vocabulary, oral and written language; digital storytelling projects creation or identity texts to write and program an interactive story under the theme; dual-language artifacts	• Linguistic scaffolding; • Culturally responsive pedagogies; • Inquiry-based learning; • Group discussion and student collaboration	• vocabulary cards; • Scratch, (programming environment)	• Formative assessment of students' discourse and artifacts; • Peer evaluation for created videos in talk and text; • Assessment of conceptual understanding; • The open-ended nature of the assignments and the possibility to reuse and build on existing works from the Scratch community for explore students at different levels of programming and language competence

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Parsazadeh et al	2021	China (Taiwan)	Primary	quantitative method	CT: Cognitive knowledge (decomposition, pattern recognition, abstraction, and algorithm design); practices and skills (problem-solving skill); attitudes and perspective (expressing, connecting, anxiety, motivation) English language content: listening and identifying story content; sentence structure; correct sequences and generalization story; writing and creating story	The method of "present, practice, and produce" was applied to present CT in the English language learning classroom with digital storytelling. Scaffold as teaching strategy for students by applying the CT strategy to scriptwriting the storytelling process.	• PowerPoint lecture; • Markers/ Whiteboard; • Paper (worksheet); • Pen/Pencil; • Internet-connected computer (one computer per student); • Scratch software	• English knowledge test; • Story evaluation rubric; • Dr. Scratch assessment tool to analyze the applied CT strategy in digital stories created by students in Scratch software; • Motivation survey; • Foreign language classroom anxiety scale

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Hsu & Liang	2021	China (Taiwan)	Primary	quantitative methods	CT: Cognitive knowledge (condition, critical thinking); practices and skills (sequential process; cooperation); attitude and perspective (connecting) English language content: Interdisciplinary content; English vocabulary and conversational sentence practice	plugged and unplugged approaches	• Control Cards in the board game; • Board game map; • Educational robots; • Teaching materials	• Pre-test to evaluate students' basic abilities and knowledge of CT and the foreign language (English proficiency); • Pre-test and post-test of learning achievement; • Learning questionnaires for the participants to self-describe their foreign language learning anxiety, cooperative tendency, and critical thinking

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Weng et al	2018	China (Hong Kong)	Primary	mixed methods	CT: Cognitive knowledge (algorithm, logic, data visualization); practices and skills (testing and debugging, problem-solving, creating digital artefact, collaborating, communication); attitude and perspectives: (expressing, connecting, questioning, confidence) English language content: English dialogues, storytelling texts, sentences, images, sound, grammar, language knowledge structures and vocabulary	visual-based programming design	Scratch	• Questionnaire survey; • Qualitative interviews

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Federici et al	2019	Italy	Primary	quantitative method	CT: Cognitive knowledge (data analysis, data collection, data representation, decomposition, pattern recognition, abstraction, automation); practices and skills (tinkering, creating, reusing, testing, debugging); attitude and perspectives (tolerance for ambiguity, the ability to deal with open ended problems) English language curriculum: vocabulary, phrases, and construction sentences	Programming-based learning	BlockLang (block-based programming languages)	A test with close-ended and open-ended questions

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Costa et al	2016	Portugal	Primary	quantitative method	CT: Cognitive knowledge (algorithm and programming, automation); practices and skills (testing, creating, debugging, communication, cooperativity, the ability to communicate and work with others to achieve a common goal or solution); attitudes and perspectives (expressing, connecting, questioning) English language curriculum: listening, reading, speaking, writing, intercultural domain, theme, and topic work	Coding and Scratch design	• Scratch; • The schoolbook and its assets	• Initial satisfaction questionnaires; • Initial placement test; • Progress assessment (language acquisition) questionnaires; • Instruments for measuring reactions

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Pektas & Sullivan	2021	USA	Primary	qualitative method	CT: Cognitive knowledge (sequence, sequencing of events, structure, coding, algorithmic development, artefact, data collection, data analysis, data representation, computing artefacts, decomposition, patterns finding, abstraction); practices and skills (creating, testing, debugging, tinkering, reusing, remixing, communication, collaboration); attitudes and perspectives (expressing, connecting, the ability to deal with open ended problems) English language curriculum: story writing, story animation creation	Interdisciplinary integration approach	• Scratch; • Graphic organizer; • A story map	Students' interview

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Liu et al	2017	China (Taiwan)	Primary	quantitative method	CT: Cognitive knowledge (pattern recognition, abstraction, creativity); practices and skills (remixing, collaboration, communication, modelling, online artefacts, data collection, data analysis, data representation, evaluation); attitudes and perspectives (expressing, connecting, questioning, confidence, persistent engagement) English language curriculum: vocabulary, sentence patterns, read and create multimedia stories, verbal and written English language, oral narrations	Remix-oriented approach: learning to generate online artefacts, hybridization, and scaffolding	• Online platform; • E-book; • A live online teaching assistant; • Skype	• Flow perception for students' engagement; • Motivated strategies for learning questionnaire (MSLQ); • Creative self-efficacy questionnaire; • Multimedia stories

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Smith & Burrow	2016	USA	Primary	qualitative method	CT: Computational concepts (sequence; loops; parallelism; events; conditionals; operators; data); computational practices (experimenting & iterating; testing & debugging; reusing & remixing; abstracting & modularizing); computational perspectives (expressing; connecting; questioning) English language curriculum: writing for multiple text types and purposes; production and distribution of writing; building and presenting knowledge; writing styles; write routinely over extended time frames (research, reflection, revision); using linking words to connect ideas within categories; writing publication to interact and collaborate with others; conducting short research projects	Inquiry-based learning and teaching	• iPad; • Scratch	N/A

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Hladik et al	2017	Canada	Kindergarten-Primary	qualitative method	CT: Cognitive knowledge (problem formulation, decomposition, pattern generalization, pattern recognition, data, algorithm, sequences, parallelism, events, conditionals, modeling, computing and society, critical thinking); practices and skills (inquiry, creative thinking, reusing, testing, debugging); attitudes and perspectives (connecting, expressing) English language curriculum: story writing	CDIO (Conceiving, Designing, Implementing, and Operating) framework	Scratch	N/A

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Strachman et al	2020	USA	Primary	qualitative method	CT: Cognitive knowledge (sequencing, events, loops, algorithms, coding concepts); practices and skills (modeling, creating) English language curriculum: Storytelling, genre, language use, reading and listening skills, story structure and building, story creation, writing skills	• Game and block-based programming design; • StoryMode features usage	Game-based and block-based programming environment	• Field notes from classroom observations; • Teachers' reflections; • Products of students' work; • Emotional response to StoryMode on a 1–5-point Likert scale

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Mannila et al	2014	USA	Kindergarten-Primary-Middle	mixed methods	CT: Cognitive knowledge (data, patterns, generalizations, abstraction, evaluation); practices and skills (modeling, operators, problem solving); attitudes and perspectives (persistence in working with difficult problems) English language curriculum: English reading and writing; diagramming sentences through syntax trees (mother/foreign languages); collocation and word frequency	• Anchor standards for reading: Integrate and evaluate content presented in diverse media and formats; • Anchor standards for writing: Use technology to produce, publish writing and to interact and collaborate with others; • Anchor standards for writing: Gather relevant information from multiple print and digital sources, assess the credibility and accuracy of source, and integrate the information while avoiding plagiarism	• Google network; • Scratch; • Alice; • Free online tools	• Questionnaire; • In-depth interviews

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Mueller et al	2017	Canada	Primary	mixed methods	CT: Cognitive knowledge (data, events, sequences); attitudes and perspectives (connecting, expressing, questioning) English language curriculum: Ontario (Canada) Elementary School English language curriculum content	• The existing curriculum already provides CT evidence and as a starting place for educators who wish to expand the curriculum to incorporate or expand CT resources	• Scratch; • Support from others at the local school: administrators, local teacher teams, and IT-personnel colleagues	• Content analysis; • Teacher verbal protocols

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Mouza et al	2017	USA	Kindergarten-Primary-Middle	mixed methods	CT: Cognitive knowledge (problem decomposition, abstraction, algorithmic thinking, sequencing events, data collection and analysis/representation, automation, critical thinking); practices and skills (problem-solving) English language content: sequencing events in a story; recalling the story to extract main ideas; essay	• TPACK-CT design; • Board games; • Robotics, and programming	• Word processor and the classroom interactive whiteboard; • A paper-based worksheet; • Concept mapping software; • Collaboration tools; • Internet resources; • Web 2.0 tools; • Programming (Scratch)	• Self-reported survey; • Case reports

Table 1 (continued)

Author (s)	Publication year	Location of the study	Educational level of the participants	Research methodology	Components of CT and English language curriculum	Implementation design	Teaching and learning resources	Evaluation methods and instruments
Zaman et al	2019	Malaysia	Primary	qualitative method	CT: Cognitive knowledge (logic, decomposition, patterns, abstraction, algorithms, evaluation); practices and skills (tinkering, visualizing the problem creatively, debugging); attitudes and perspectives (persevering, connecting) English language content: dialogues and writing; STEM problems solving as interdisciplinary content in English lessons	• Collaborative Computational Thinking Design Practices (CCTDP) framework with problem solving orientations; • Multimodal interactive approach; • Peers' cooperation	• White board; • Visual diagram; • Computers; • Videos	• Observational assessment; • Digitally captured video-recordings of students undergoing actual English lessons across STEM; • Artifacts such as lesson plans, drawings, 'handouts' as well as text and visual diagrams on 'rough papers', 'mahjong papers' and small portable whiteboard

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